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SOURCES OF STONES USED IN PREHISTORIC MESOAMERICAN SITES

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A N N O U N C E M E N T

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SOURCES OF STONES USED IN PREHISTORIC

MESOAMERICAN SITES

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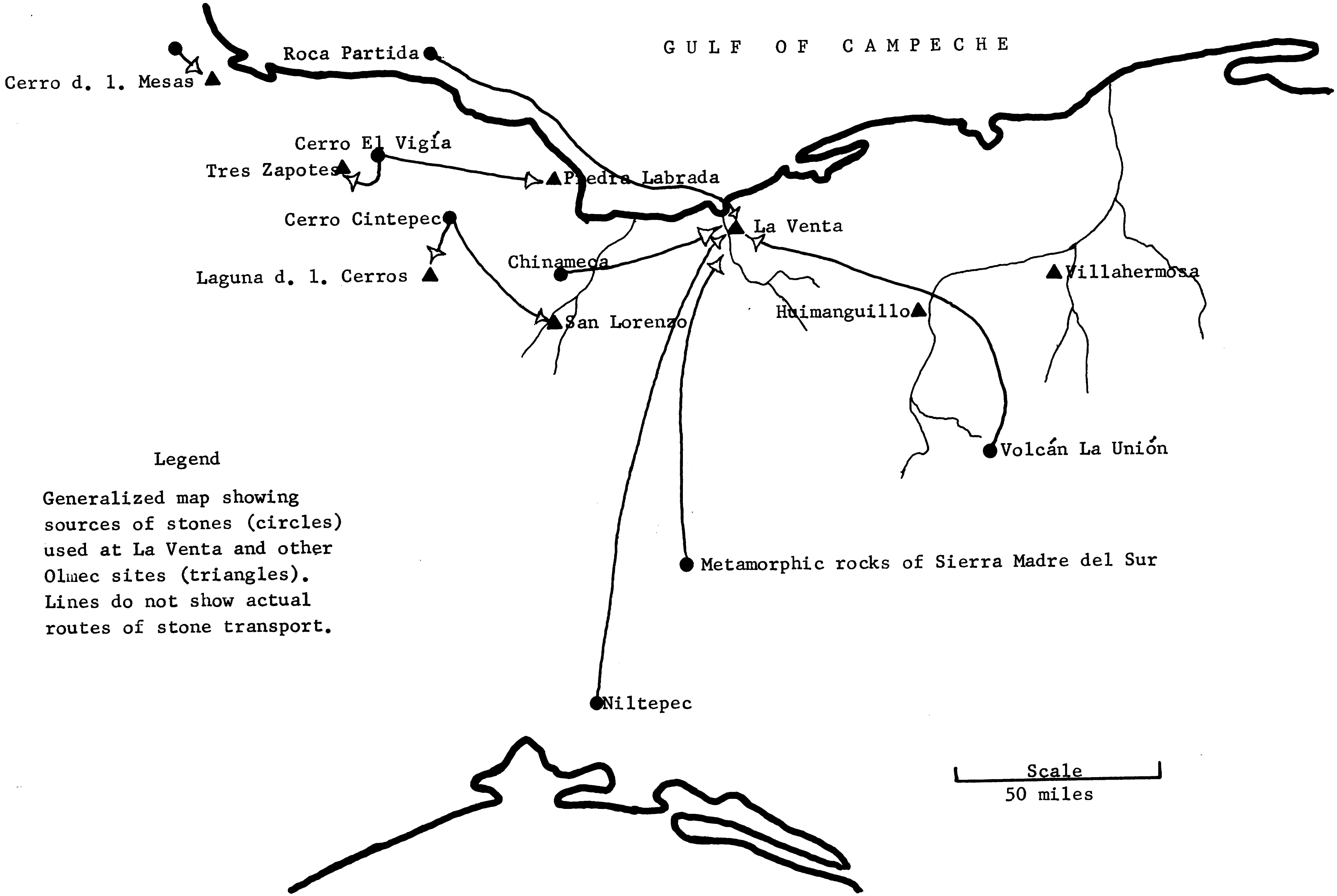
GULF OF CAMPECHE
Cerro d. l. Mesas
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Niltepec
Scale
50 miles
Legend
Generalized map showing sources of stones (circles) used at La Venta and other Olmec sites (triangles). Lines do not show actual routes of stone transport.

Map 1

SOURCES OF ROCKS USED IN OLMEC MONUMENTS

Howel Williams and Robert F. Heizer

INTRODUCTION

This paper provides information on the question of the sources of the stones used by the Olmecs—the designation applied to a prehistoric people living during the first millennium B.C. on the lowland Gulf of Mexico coastal plain in what are now the Mexican states of Veracruz and Tabasco—to carve their altars,[1] stelae, and colossal heads. The data contained herein supersede that reported in Heizer and Williams, 1960. There has been agreement among those interested in this question that most of the rocks, despite their great size and weight, must have been transported for very long distances, and an answer to the problem of provenience must be found before a satisfactory estimate can be made of the total labor involved in constructing the Olmec ceremonial sites[2] or the means and routes by which multiton stones[3] were transported to the sites. Map 1 shows a generalized delineation of source localities of stones.

We spent the last two weeks of January, 1960, examining the geology of the Tuxtla Mountains, visiting the La Venta site, inspecting the Olmec monuments housed in the museum and in the outdoor museum called the Parque Olmeca or La Venta Park at Villahermosa, in the Museo Jalapa, and in the Museo Nacional de Antropología in Mexico City. During part of this time we were fortunate in having the company of Dr. Philip Drucker. We returned to Mexico during the last week of January, 1962, and again for a few days during the following June, to continue our reconnaissance of the Tuxtla Mountains, to examine volcanic rocks exposed in the mountains south of Villahermosa, and to study the Olmec monuments acquired during the interim by the Museo Jalapa.

The late Ing. Hugo Contreras of Petroleos Mexicanos in Coatzacoalcos, and his successor Ing. Roberto Gutierrez Gil, gave us much valuable geological information and were of great help in providing transportation on several of our trips. We are also grateful to Dr. Alfonso Medellin Zenil and to Drs. Roberto and Jorge Williams of the Museo Jalapa who kindly assisted us in many ways, to Sr. Carlos Sebastian Hernandez, Conservador of the Museo Regional in Villahermosa, and to Dr. Philip Drucker who not only accompanied us in the field but also collected a suite of specimens for us from the vicinities of Huazuntlan and Soteapan. Finally, we thank the Committee on Research, the Associates in Tropical Biogeography, and the Archaeological Research Facility, all of the University of California, Berkeley, for generous financial aid.

Petrographic methods have long been used as an aid in the study of ancient pottery, but far too little use has been made of such methods in the study of other artifacts, particularly of stone monuments (Wallis 1955; Shotten 1963). The sources of rocks at Stonehenge have been determined (Atkinson 1956) and similar studies have been made in Egypt (Lucas 1962) and Bolivia (Ahlfeld 1946). Bell (1947) has shown the wide network of trade implied by the varied and distant sources of stone, copper, and shells found at the Spiro site in Oklahoma. Recent investigation of the trace-element composition of Mediterranean obsidians has thrown a great deal of new light on prehistoric trade contacts (Cann and Renfrew 1964). In Mexico petrology in the service of archaeology is no new thing, as a reading of the works of Fischer (1877) and Ordoñez (1892) will demonstrate. Our experience in Mexico, Guatemala, Peru, and Bolivia shows that, in general, examination of the weathered surfaces of monuments by means of the hand-lens alone is unsatisfactory. Accurate identification is often impossible, even by a specialist, without microscopic inspection. We emphasize therefore that when comparing rocks used in ancient implements or monuments and attempting to identify their sources, it is essential for the geologist to get fresh chips for microscopic study. Even chips between half an inch and an inch across and a quarter of an inch thick will suffice to prepare the thin sections the geologist needs for study under the petrographic microscope.[4] If the archaeologist thinks that a monument or other artifact would be seriously damaged by removal of a chip, he should if possible permit the geologist to scratch a little powder from the specimen. Damage done by discreet chipping or scratching will almost always be trivial compared with the scientific results to be obtained. One purpose of this report is to stress the need for closer cooperation between the archaeologist and the geologist in the study of ancient stone artifacts.

In the pages which follow we discuss first the geological setting of the Olmec sites—particularly the nature and distribution of the volcanic and metamorphic rocks which the Olmecs used extensively—and then examine in more detail the petrographic characters of the rocks from which some of the monuments were carved.

GEOLOGICAL SETTING OF THE OLMEC SITES

Most Olmec monuments[5] are carved from volcanic rocks, a minority are fashioned from metamorphic rocks (Curtis (1959). It seems proper, therefore, that we begin by describing the volcanic fields adjacent to the lowland Olmec sites in Veracruz and Tabasco.

Tuxtla Mountains

The Tuxtla Mountains lie close to the heart of the Olmec country. They consist predominantly of volcanic rocks that were laid down on an eroded basement of Early and Middle Tertiary sedimentary rocks, some of which are to be seen along the western and southwestern flanks of the mountains (Maps 1, 2).

Two groups of volcanic rocks are easy to distinguish; namely, a Plio-Pleistocene group of lavas, pyroclastic rocks, and tuffaceous sediments, especially widespread on the southwestern side of the Tuxtla Mountains; and a younger group of Late Pleistocene and Recent age that forms most of the opposite side, including the huge cones of San Martín Tuxtla, San Martín Pajapan, Santa Marta, and Pelón. Topographic forms within the belt occupied by the younger group are only slightly modified by erosion so that the eruptive vents and constructional slopes of the volcanoes are easy to detect. Within the belt occupied by the older group no original volcanic forms persist, the landscapes there being almost entirely the product of erosion.

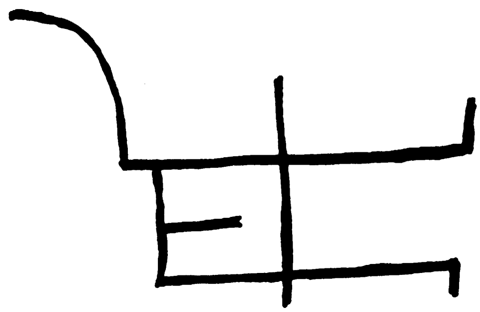
Virtually nothing had been published concerning the geology of the Tuxtla Mountains prior to Friedlaender's account of a reconnaissance he made in 1922 and Sonder's accompanying account of the specimens that Friedlaender collected (Friedlaender and Sonder 1923). Unfortunately for the present purpose, their main concern was with the younger Quaternary volcanoes and their products rather than with the Plio-Pleistocene volcanic rocks which supplied most of the materials employed by the Olmecs. Between 1950 and 1952 three papers were published by petroleum geologists concerning the Tuxtla region. As might be expected, these deal principally with the stratigraphy of the marine Tertiary beds and with the general structure rather than with the petrography of the volcanic rocks. Particularly noteworthy in the present connection is the paper by R. Ríos Macbeth (1952). In 1962 F. Mayer Perez Rul published a volcanological study of the region based mainly on examination of aerial photographs, and therefore concerned much more with geomorphology than with petrography.

Plio-Pleistocene volcanic rocks: Volcanism began in the Tuxtla region at least as early as Oligocene times, as shown by the presence of marine tuffaceous sediments of that age, and it has continued intermittently ever since. Seas retreated from the region about the close of the Miocene period; then, following an interval of erosion, subaerial volcanoes began to erupt during the Pliocene period.

Plio-Pleistocene lavas are poorly exposed in the country adjoining the highway between Santiago Tuxtla and San Andrés Tuxtla, where they consist mainly of fine-grained, olivine basalts and perhaps also of andesites interbedded with tuffaceous sediments. None of these rocks resemble those which the Olmecs carved.

About 4 kilometers west of Santiago Tuxtla, however, there is a conspicuous ridge that culminates in the peak formerly called Cerro Santiago but now known as Cerro El Vigía. This was undoubtedly a principal source of Olmec lithic material, especially for the nearby site of Tres Zapotes. Friedlaender was told that Cerro El Vigía was sacred to the Indians and that some of the lavas from there had been used for monuments, specifically for making two stone rabbits and a toad, which Friedlaender states were formerly kept in Santiago Tuxtla but are now in the plaza at San Andrés Tuxtla (cf. Blom and La Farge 1926:I:19; Seler-Sachs 1922:pl. 5, no. 2). Friedlaender was the first to call attention to the exceptionally coarse-grained nature of the olivine- and augite-rich basalts (fig. 4a) which are widespread on the upper slopes of Cerro El Vigía. Our observations show that many Tres Zapotes monuments were carved from these distinctive basalts, among them the following: Tres Zapotes Colossal Heads No. 1 (Stirling 1943:pl. 4) and No. 2 (Heizer, Smith and Williams 1965); Monument F (Stirling 1943:pl. 8a); a rectangular stone basin adorned with pecten shells (illustrated here in pl. 1a, and earlier by Blom and La Farge 1926:I:fig. 24) now to be seen in the plaza of Santiago Tuxtla; Monument C, also from Tres Zapotes (now in the Museo Nacional in Mexico City); Monument 9 from San Lorenzo (Stirling 1955:pl. 18b); and two unpublished sculptures which we refer to in our notes as the "Frog Altar" and "Jaguar Throne" from Piedra Labrada and now in the Museo Jalapa. We do not doubt, even though we were unable to visit the Tres Zapotes site, that there exist locally other Olmec monuments carved from the basalts of Cerro El Vigía.

It was from the upper slopes of Cerro El Vigía, close to the summit, that the Olmecs secured much of the material they carved. Hereabouts the massive, coarsely porphyritic basalts have been weathered spheroidally so that the slopes are littered profusely with huge, round, smooth-faced boulders, some more than 3 meters in diameter. On one



Scale

1 foot

Figure 1. Petroglyph on boulder on Cerro El Vigía

boulder we found some crude petroglyphs (illustrated above) but as far as we know, no sculptured monuments have been found among them. Presumably the Olmecs rolled or dragged the boulders downslope before they began to carve them.

We found no likely sources of stone material in the country directly south of San Andrés Tuxtla and west of the highway. The Plio-Pleistocene rocks thereabouts, though deeply eroded, are poorly exposed; some valleys incised in them are partly filled by Recent flows of dark, fine-grained basalt such as that which produces the beautiful waterfall known as El Salto de Eyipantla, just south of San Andrés Tuxtla.

Along the southern flanks of the Tuxtla Mountains, particularly on the slopes of Cerro Cintepec and in the vicinity of Soteapan and Huazuntlan, the alluvial fans contain many large boulders of coarsely porphyritic olivine-augite basalts indistinguishable from many of the rocks used by the Olmecs at La Venta, San Lorenzo, and adjacent sites. Some of the boulders that we saw measured 3 meters across, scores of them measured approximately 2 meters across. We did not have time to trace the boulders to their source, but this must be on and near the top of Cerro Cintepec where the boulders must be even larger and still more numerous. In our opinion this area was almost certainly the main source from which the Olmecs derived their volcanic stones, and we believe that the material they used was not quarried from lavas *in situ* but was selected from detached and rounded boulders in the alluvial fans. Unfortunately we were unable to reconnoiter the slopes north of Volcán San Martín Pajapan which, according to F. Mayer Perez Rul (1962) are also occupied by Plio-Pleistocene lavas, but after flying over these deeply dissected, heavily wooded slopes, we doubt that the Olmecs obtained any of their materials there.

Late Pleistocene and Recent volcanic rocks: The four principal Quaternary volcanoes of the Tuxtla Mountains—San Martín Tuxtla, San Martín Pajapan, Santa Marta, and Pelón—are aligned in a northwest-southeast direction, roughly parallel to the adjacent coast line of the Gulf of Campeche. Each major volcano bears on its thickly wooded flanks a cluster of smaller, parasitic cinder cones such as may be seen close to the highway between San Andrés Tuxtla and Lake Catemaco and close to the margins of the lake itself. All of the major volcanoes and many of their parasites have erupted within the last few thousand years, indeed San Martín Tuxtla discharged lavas and cinders as recently as 1793 (Mozino 1913; Friedlaender and Sonder 1923). The Olmecs undoubtedly witnessed and suffered from many of these outbursts.

All of the lavas collected by Friedlaender and described by Sonder from these youthful volcanoes, and all that we saw around Lake Catemaco, are dark, vesicular, olivine-augite basalts which, though similar mineralogically to the older basalts of Cerro El Vigía and Cerro Cintepec, are texturally quite different in lacking the large and abundant phenocrysts that typify most of the older basalts and having a very much finer-grained groundmass. None of the Quaternary basalts that we examined resembled the basalts of the sculptured Olmec monuments. Nevertheless we think that the basalt columns that were used extensively at La Venta, in the tombs, entryways, platforms, and Ceremonial Court, were almost surely derived from Quaternary flows.

Dr. Alfonso Medellin Zenil informed us of the occurrence of columnar basalts near the Hydroelectric Plant in the canyon of Río Huazuntlan, close to the localities from which we believe that the Olmecs obtained much of their sculpture material. At our request Dr. Philip Drucker kindly collected samples of these columnar basalts from both the Huazuntlan and Soteapan falls, as well as samples from boulders on the intervening slopes. The bouldery material resembles that from the slopes of Cerro Cintepec and some of it may well have been used by the Olmecs, but the columnar basalts are quite different from those employed at La Venta. The latter (see fig. 2c) are pale gray lavas crowded with large crystals of fresh olivine and are quite devoid of phenocrysts of feldspar. The columnar basalts from Huazuntlan and Soteapan, on the contrary, are dark gray lavas carrying abundant large, subparallel laths of feldspar, almost completely devoid of olivine and augite phenocrysts; moreover, the few olivine crystals which they contain show extensive alteration to greenish serpentine. Besides, as Dr. Drucker informs us, most of the columns in the basalts at Huazuntlan and near Soteapan are much larger than those used at La Venta, some of them having maximum diameters of about 4 feet, and most having minimum diameters of about 2 feet. It would have been extremely difficult to transport such heavy columns from the deep gorges in which they are found. Accordingly the source of the La Venta columns must be sought elsewhere, and we suggest that it may have been from the islet close to the coast near Punta Roca Partida (see pl. 1b).

One of us (H.W.) flew northwestward along the coast from Coatzacoalcos with the late Ing. Hugo Contreras of Petroleos Mexicanos. Almost all of the cliffs over which we flew seemed to be cut out in thin sheets of basalt separated by layers of basaltic tuff and scoria. Along the northern base of San Martín Tuxtla volcano, west of the hamlet of Montepío, we flew over two conspicuous headlands. On one headland, Punta Organo, we saw thin, steeply dipping dikes of basalt cutting beds of rotten scoria; on the other, Punta Roca Partida (a photograph of which is shown in Friedlaender and Sonder 1923), we saw a large body of columnar basalt cutting thick deposits of cross-bedded scoria. Friedlaender was certainly correct in saying that this second headland marks the remains of a parasitic cone. Not far to the west, very close to the shore, we flew over a rocky islet of columnar basalt, perhaps the remnant of a lava flow from this cone (pl. 1b). Friedlaender's map shows that he collected a sample here but unfortunately Sonder did not describe it, and we were unable to collect a specimen for ourselves. It is important, therefore, that the islet be revisited for we think that the Olmecs of La Venta may have obtained their basaltic columns here.[6] It would not have been difficult to snap off the columns at their base, load them on rafts during the calm weather, and transport them along the coast to the mouth of Río Tonala, 130 kilometers to the southeast, and thence upstream for another 16 kilometers or so to La Venta. Such an operation would have been simpler than transporting commensurate columns overland for much shorter distances.

It is appropriate to add that nowhere in the Tuxtla Mountains did we find any sources of the obsidian which the Olmecs used, nor did we find any fragments of obsidian in the beds of any of the rivers that drain down from the mountains south of Villahermosa. The most abundant source of obsidian that we know of in Central America is in the southeastern part of Guatemala, particularly on the volcano known as Ixtepeque, and on the adjacent volcanoes of Laguna de Obrajuelo and Agua Blanca. Smaller occurrences of obsidian are scattered through the highlands west of Guatemala City (Coe and Flannery 1964), but the nearest of these Guatemalan sources lies approximately 500 kilometers from the Olmec country, and the great obsidian fields of Ixtepeque lie more than 600 kilometers away. Perhaps the Olmecs got some of their obsidian from these distant sources, but more likely there were sources nearer to hand—somewhere in the Mexican volcanic province to the north and west (cf. West 1964). X-ray fluorescence analysis of nine obsidian samples is described and commented upon in two brief papers appearing in the present volume.

La Unión Volcano

This Quaternary volcano, which is still in a solfataric stage of activity, was first identified as such by Mullerried (1933) who described it under the name of El Chichón. It lies on latitude 17° 20' N. and longitude 93° 12' W., approximately 60 kilometers S. 20° W. of Villahermosa and twice that far southeast of La Venta.

The volcano has a steep-walled summit-crater with a breach on its southwest side. A huge pelean dome rises from the floor of the crater, its top towering high above the crater-rim, and a thick flow of lava extends from the base of the dome through the breach toward Río Osthuacan.

Mullerried identified a rock from the summit of the volcano as hornblende andesite, and all of the six samples collected for us through the help of the late Ing. Hugo Contreras are also hornblende andesites. In addition all of the lava boulders that we examined in the bed of Río Osthuacan, close to the village of that name, were composed of exactly the same kind of andesite. A few boulders measured as much as 2.5 meters across though they lie 12 kilometers downstream from their source. Closer to the volcano there must be more and even larger boulders.

Here it should be noted that three of the Olmec monuments found at La Venta appear to have been carved from the La Unión lava; namely Altar 7 (see p. 20), a monument depicting a monkey with the hands clasped behind its head, said to have been bulldozed from the La Venta site some time between 1956 and 1960 (both of these are now to be seen in the La Venta Park in Villahermosa), and Monument No. 21 from La Venta (Drucker, Heizer and Squier 1959:pl. 51a), now in the Museo Villahermosa. In addition we found many broken fragments of pale gray hornblende andesite, identical with that from La Unión volcano, in a recently opened pipeline trench on the north side of the La Venta site. No comparable andesites have been observed by us in the Tuxtla Mountains nor among the Tertiary lavas in the mountains south of Villahermosa. It seems reasonably certain therefore that the Olmecs of La Venta obtained some of their lithic materials either from La Unión volcano itself or from boulders in the bed of the river that drains its slopes. Thence to La Venta transport may have been by way of water, though there is a short stretch of the Río Osthuacan above the village of Sayula where the river runs through a rocky gorge that would have been difficult, if not impossible, to negotiate in heavily loaded rafts.

Tertiary Volcanic Rocks Near Teapa

Remnant patches of Tertiary lavas are widespread among the mountains south of Villahermosa, but as far as we have been able to tell none of these lavas were used by the Olmecs.

In the foothills stretching westward from Teapa to near Pichucalco, 13 kilometers away, all of the lavas that we saw were hornblende-rich, biotite-bearing dacites or rhyodacites characterized by large crystals of quartz. Interbedded with these flows are tuffaceous sediments and volcanic conglomerates.

Pebbles, cobbles, and boulders carried down from the mountains by the Río Teapa are composed mainly of hornblende diorite. Why the Olmecs made no use of these rocks poses an interesting question, for they are attractive and well suited to sculpture. Perhaps their hardness or small size discouraged their use for this purpose. The volcanic detritus accompanying the diorites consists almost entirely of pyroxene- and hornblende-andesite. Some of it consists of hornblende-biotite dacite, but olivine-augite basalt, if present, must be very rare.

In the bed of Río Puyacatengo, about 3 kilometers east of Río Teapa, and in the intervening area, almost all of the volcanic rocks are dense, dark bluish-gray, vitrophyric hornblende andesites; a few are hornblende-bearing pyroxene andesites. None of these andesites resemble those of La Unión volcano, and coarsely porphyritic olivine-augite basalts, similar to those used in most of the Olmec monuments, are conspicuously absent.

Finally, in the bed of Río Tacotalpa, 16 kilometers east of Teapa, most of the debris is composed of foraminiferal limestones and metamorphic rocks. Among the sparse volcanic debris are some cobbles of hornblende-biotite dacite, but most consist of dense, vitrophyric types of hornblende- and pyroxene-andesite, quite unlike any of the lithic materials used by the La Venta Olmecs.

Cerro Acalapa and Arroyo Sonso

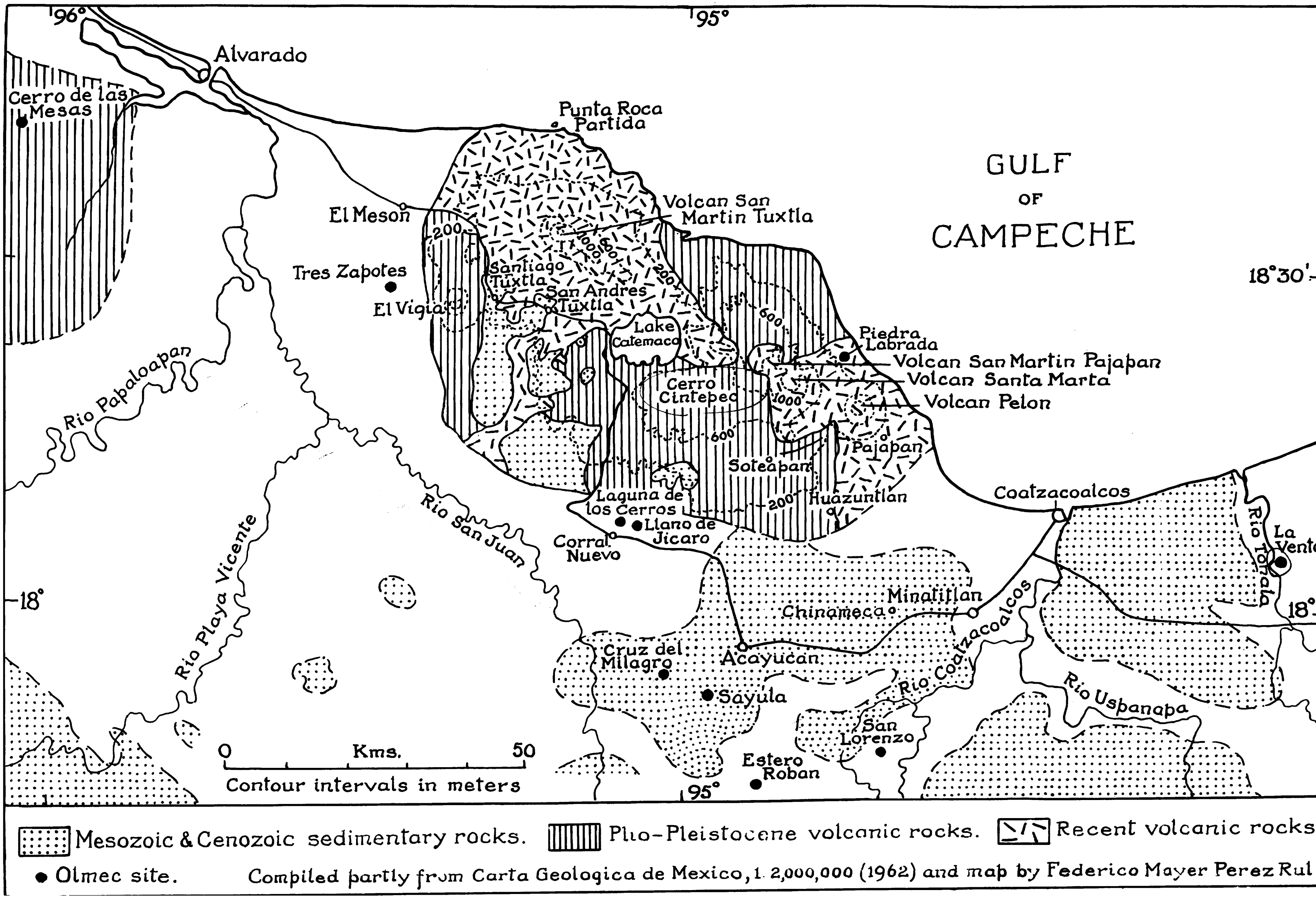
Blom and La Farge (1926) mention that they were told of exposures of igneous rocks not far from La Venta, along the road between Minatitlan and Las Choapas, and they and others have suggested that the Olmecs may have obtained some of their materials from this region. But when we visited the area and climbed the Cerro Acalapa, accompanied by Ing. Roberto Gutierrez Gil, we found no lava flows nor any pyroclastic deposits. The only rocks thereabouts are Tertiary sediments, some of which contain small pebbles and a few cobbles of igneous rocks. This entire area may therefore be eliminated as a possible source of materials for the Olmec monuments.

Cerro de las Mesas and Vicinity

The Olmec site of Cerro de las Mesas lies close to the edge of an extensive belt of Cenozoic volcanic rocks (maps 2, 3). Unfortunately, we found no literature dealing with the character of these rocks and were unable to examine the region ourselves except in a cursory fashion. It appears, however, that before the imposing Quaternary volcanoes of Orizaba and Cofre de Perote began to grow, a thick sequence of Tertiary lavas, pyroclastic rocks, and tuffaceous sediments had been laid down in this region. No geologist seems to have described Cofre de Perote, but Waltz (1910) says that the lavas of Sierra Negra to the south are hypersthene-augite andesites and that the youngest flows of Orizaba are hornblende- and pyroxene-andesites, some with and some without hypersthene.

Through the good offices of Dr. Matthew Stirling, we obtained small fragments from seven of the monuments at Cerro de las Mesas and one from the nearest volcanic outcrop, at the intersection of the road from Piedras Negras with the Cordoba-Veracruz highway. The outcrop sample is a hornblende andesite tuff crowded with vitric, crystal, and lithic fragments. Bits of varitextured andesite are mingled with crystals of plagioclase, fewer of olive-green and russet hornblende, and still fewer of hypersthene and pale green augite. These constituents lie in a micropumiceous matrix of glass shards and dust. What is important in the present connection is to note that all but one of the samples from the monuments at Cerro de las Mesas are composed of hypersthene-bearing hornblende andesite lava; the exception (Stela 3) is an andesite tuff essentially similar to the outcrop sample just described. This suggests that lavas of the same mineralogical composition are present not far away, and that these localities supplied most of the rocks required.

Since all of the rocks from Cerro de las Mesas that we examined contain hypersthene, whereas none of those used in the Olmec sites to the


96°
95°
Alvarado
Cerro de las Mesas
Punta Roca Partida
GULF
OF
CAMPECHE
El Meson
Volcan San Martin Tuxtla
200
1000
800
Tres Zapotes
Santiago Tuxtla
San Andres Tuxtla
El Vigia
18°30'
Lake Catemaco
600
Piedra Labrada
Volcan San Martin Pajapan
Volcan Santa Marta
Volcan Pelon
Cerro Cintepec
Rio Papaloapan
Pajapan
Soteapan
Huazuntlan
Coatzacoalcos
Laguna de los Cerros
Llano de Jicaro
Corral Nuevo
Rio San Juan
Rio Playa Vicente
Rio Tonala
La Venta
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Minatitlan
Chinameca
Rio Coatzacoalcos
Cruz del Milagro
Acayucan
Sayula
Rio Uspanapa
San Lorenzo
Estero Roban
0
Kms.
50
Contour intervals in meters
Mesozoic & Cenozoic sedimentary rocks.
Plio-Pleistocene volcanic rocks.
Recent volcanic rocks.
Olmec site.
Compiled partly from Carta Geologica de Mexico, 1. 2,000,000 (1962) and map by Federico Mayer Perez Rul.

Map 2

east contain this mineral, we conclude that there was probably no transfer of lithic material from one region to the other.

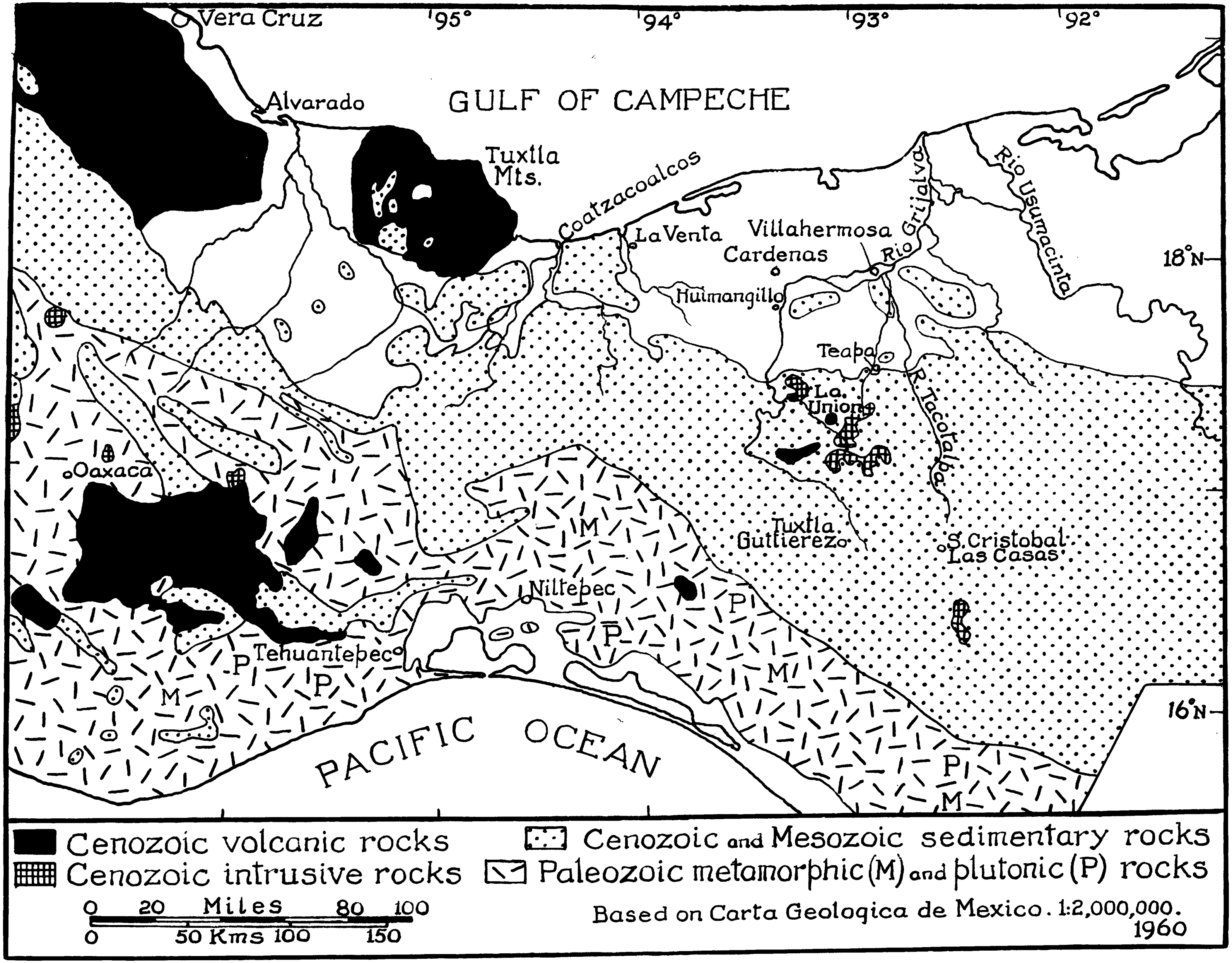
Metamorphic Terrains

Until more field work is done there is little to add to what Curtis (1959) has already written about the nature and provenience of the metamorphic rocks used by the Olmecs at La Venta. His list included the following types: pumpellyite schist, muscovite-actinolite schist, actinolite schist, actinolite-epidote gneiss, quartzite, and several varieties of meta-andesite or metadiorite, serpentine, and jadeite. Two other types can now be added to his list—these are from unpublished monuments recently (post-1955) included in the collection at La Venta Park in Villahermosa. One of these monuments is composed of chlorite-actinolite-epidote-albite-sphene schist containing many small porphyroblasts of magnetite; the second is an incompletely sculptured block 8 feet long, 40 inches high, and 44 inches wide, which looks at first glance like a solid concrete park bench. It is composed of chlorite-muscovite schist riddled with stringers and lenses of coarsely granular quartz. This monument is thus far unnumbered and unpublished and is designated as No. 27 in the Parque Olmeca.

All of these metamorphic rocks are characteristic of the greenschist facies of metamorphism, and without doubt, as Curtis says, all came from the belt of Paleozoic rocks that forms part of the Sierra Madre del Sur (map 3). Ing. Roberto Gutierrez Gil tells us that there are serpentines near Niltepec, and other serpentines probably await discovery elsewhere in the adjacent mountains. We do not doubt that it was from the bed of a stream draining areas of serpentine and related ultrabasic rocks in these mountains that the Olmecs obtained the waterworn cobbles of ilmenite from which they fashioned their amazingly perfect concave mirrors (Gullberg 1929).

Chinameca Limestone

Limestones of Late Jurassic and Early Cretaceous age are present on the small hill east of the village of Chinameca, approximately 60 kilometers from La Venta, where they have been uparched by the rise of a subterranean salt dome. Many slabs of these limestones were used for building materials at La Venta. As Map 2 shows, Chinameca lies roughly midway between La Venta and the slopes of Cerro Cintepec from which the Olmecs obtained most of the volcanic rocks they used for their monuments.


Vera Cruz
95°
94°
93°
92°
Alvarado
GULF OF CAMPECHE
Tuxtla Mts.
Coatzacoalcos
La Venta
Villahermosa
Cardenas
Rio Grijalva
Rio Usumacinta
18°N
Huimangillo
Teapa
La Union
R. Tacotalpa
Oaxaca
Tuxtla Gutierez
S. Cristobal Las Casas
Niltepec
Tehuantepec
M
P
16°N
PACIFIC OCEAN
Cenozoic volcanic rocks
Cenozoic intrusive rocks
Cenozoic and Mesozoic sedimentary rocks
Paleozoic metamorphic (M) and plutonic (P) rocks
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0 50 Kms 100 150
Based on Carta Geologica de Mexico. 1:2,000,000. 1960

Map 3

PETROGRAPHIC NOTES ON VOLCANIC ROCKS USED FOR OLMEC MONUMENTS

Monuments from Cerro de las Mesas

Thin sections were prepared from six samples sent to us by Dr. Matthew Stirling. We hope that the following descriptions will facilitate the search for the sources from which the rocks were derived.

Stela 3: This is composed of hornblende andesite tuff (fig. 3b) essentially similar to the outcrop sample collected not far away by Dr. Stirling. Approximately a third of the tuff consists of angular chips of colorless and pale gray glassy andesite ranging in size from minute specks to a diameter of 5 mm. Many of these chips exhibit perlitic cracks. About half of the tuff consists of broken phenocrysts of plagioclase that show oscillatory zoning and a range in composition from sodic bytownite to medium labradorite. There are also many phenocrysts of olive-green hornblende, a few of hypersthene and pale green diopsidic augite, and rare minute flakes of biotite. Quartz and sanidine seem to be absent.

Stela 4: A porphyritic, pilotaxitic oxyhornblende-hypersthene andesite. About 40 per cent of this lava consists of labradorite-bytownite phenocrysts with pronounced oscillatory zoning and a maximum length of about 2 mm. Approximately a third consists of reddish brown crystals of oxyhornblende, many of them fringed with magnetite. Almost all of these hornblendes measure less than 0.25 mm. in length, but a few exceed 2.0 mm. Stumpy subhedral prisms of hypersthene, none more than 0.25 mm. in length, constitute about 5 per cent of the bulk; augite is much less plentiful. The remainder of the lava is a dense, porous pilotaxitic groundmass of oligoclase microlites and interstitial 'cryptofelsite,' and many of the irregular pores are partly lined with minute spheroids of cristobalite.

Monument 6: An andesite similar to that in Stela 4 above, illustrated in Figure 3c.

Stelae 8 and 9: These are carved from tridymite-rich oxyhornblende andesites (one of which is illustrated in fig. 3a). Both samples are characterized by abundant phenocrysts of brown hornblende, some of them 3 mm. long, almost wholly replaced by dense intergrowths of granular augite and magnetite. Zoned phenocrysts of plagioclase, though fewer, are generally of the same size and composition as those in the andesites already described; the same can be said of the subordinate small phenocrysts of hypersthene. The pilotaxitic matrix is marked especially by many clear, porous patches rich in tridymite and by the presence of a little fumarolic hematite-dust.

Stela 10: A fine-grained hornblende andesite. This lava contains many slender prisms of olive-green hornblende 1.0 mm. or less in length, and zoned crystals of plagioclase of the same size, accompanied by a few minute crystals of hypersthene and augite in a dense pilotaxitic matrix.

Two monuments housed in Museo Jalapa and labeled "Late Cerro de las Mesas" were examined with a hand lens. One of these monuments depicts the head of a rain-god; it consists of pale gray, vesicular porphyritic hornblende andesite, many of the hornblendes measuring as much as 1.0 cm. in length. There are a few recognizable grains of pyroxene, but phenocrysts of plagioclase were not detected. This andesite is almost surely from the same source as those described above. The other monument, however, is composed of extremely fine-grained, dark gray basalt containing many slender laths of plagioclase in an irresolvable groundmass devoid of identifiable minerals.

Monuments from Tres Zapotes

Three monuments were examined in the plaza of Santiago Tuxtla, all of which are reported to have come from Tres Zapotes. One of the Tres Zapotes monuments is a giant head designated Tres Zapotes Colossal Head No. 2 (Heizer, Smith and Williams 1965) and the other (Monument F) depicts a reclining figure in the form of a large tenon (Stirling 1943:pl. 8a). These monuments are carved from the same distinctive basalt as were the following: Monument C from Tres Zapotes, now housed in the Museo Nacional in Mexico City; Monument 9 from San Lorenzo, now housed in the Museo Jalapa; and the unpublished "Frog Altar" and "Jaguar Throne" from Piedra Labrada, also in Jalapa. What makes this basalt distinctive is the unusual abundance of large crystals of olivine and augite, and the paucity of large crystals of plagioclase. Identical basalt, as we have noted, is widespread on the upper slopes of Cerro El Vigía where it occurs as huge spheroidal and ovoid boulders.

There is considerable variation in the proportion of the phenocrysts and in the augite-olivine ratio in the coarse-grained, picritic basalts of El Vigía. Generally, however, the olivine and augite phenocrysts each make up approximately a quarter of the total volume and range in size from 0.5 to 5.0 mm. Exceptionally, some of the stumpy augites measure as much as 2.5 cm. across. In hand specimens the olivine crystals appear pale green, in thin sections they are colorless except for thin rims of russet colored iddingsite. The augite crystals, which appear black in hand specimens, generally show a pale yellowish green color in thin sections, though some of them exhibit a beautiful and delicate oscillatory zoning, almost colorless shells alternating rapidly with greenish ones. The optic angles of the augites vary between 55° and 60°, and all show strong inclined dispersion. Plagioclase, which makes up about 40 per cent of the typical basalt, never forms large phenocrysts but occurs as divergent laths, mostly between 0.25 and 0.5 mm. in length, but occasionally as much as 1.0 mm. long. In composition it varies only slightly from medium labradorite. The remaining tenth of the basalt consists of minute granules of iron ore and augite, fine needles of apatite, and flakes of hematite.

Stela C from Tres Zapotes (Stirling 1939, 1940; Thompson 1941; Coe 1957), now in the Museo Nacional in Mexico City, is carved from a quite different kind of basalt, essentially identical with that used in making La Venta Stela 3 and the basalt of the columns surrounding the plaza or "court" at La Venta. We cannot be certain, but probably all came from the same source. All are characterized by an abundance of small phenocrysts of olivine and an absence of phenocrysts of augite and plagioclase. Approximately 15 per cent of the dense, intergranular basalt used to make Stela C at Tres Zapotes consists of ovoid crystals of fresh olivine, mostly less than 0.5 mm. in maximum dimension but occasionally about 1.0 mm. across. The remainder consists of divergent, slender laths of plagioclase, subhedral grains of augite, and iron ore. The fact that Tres Zapotes Stela C is not carved from the same stone as most of the other sculptures at this site (which came from nearby Cerro El Vigía) but is made of a stone which was more abundantly used at the La Venta site is of especial interest since it raises the possibility that Stela C may have been carried to Tres Zapotes from another site, possibly from La Venta itself, though it seems to date from after the abandonment of the La Venta site. Stela C is unique in bearing an early date (Stirling, 1939, 1940; Coe 1957) and is the only monument of its kind attributable to the Olmecs.[7]

A darker, slightly more vesicular but otherwise similar basalt was used to make the rectangular basin ornamented with *Pecten* shells to be seen in the plaza of Santiago Tuxtla and reported to have been brought from Tres Zapotes (pl. 1*a*).

Monuments from San Lorenzo and Adjacent Sites

A ~~magnificent~~ collection of monuments from San Lorenzo and other sites to the south of the Tuxtla Mountains is to be seen in Museo Jalapa. Most of these monuments, including the justly famous giant heads from San Lorenzo discovered by Matthew Stirling (as well as many of the monuments from La Venta which are in Mexico City or Villahermosa), are carved from essentially identical basalts derived from the slopes of Cerro Cintepec and the vicinity of Soteapan. Among the monuments from this area we include the following:

a. San Lorenzo: All of the giant heads (Monuments 1, 2, 3, 4, 5) as well as Monuments 10 and 11 (Stirling 1955)

b. Potrero Nuevo, near San Lorenzo: Monument 2

c. Llano de Jicaro: Monument 8, called "Señor de los Animales" of "La Divinidad del Monte" (Medellin 1960:pl. 22)

d. Estere Rabón, Sayula: Monument 5 (Medellin 1960:pl. 1)

e. Corral Nuevo: Monuments 1 and 28

f. Laguna de los Cerros: Monuments 3, 5, 9, 11, and 19 (Medellin 1960)

g. La Cruz del Milagro: (unpublished monument)

h. Cuenca de Coatzacoalcos (pl. 2*a*,*b*): Small, hunched jaguar figure (unpublished)

In addition to the foregoing monuments in Museo Jalapa, the following monuments from La Venta are carved from the same kind of basalt: Colossal Head No. 2 (earlier known as Monument 2) in Museo Villahermosa; and the following monuments housed in La Venta Park at Villahermosa: Altars 1, 3, 4, 5, 6, and 10, as well as Monument 13. Monuments 19 and 23 from La Venta, now housed in the Museo Nacional, Mexico City, also ~~appear to~~ have been carved from the same basalt.

No useful purpose would be served by describing the slight variations to be noted in the textures and proportions of the constituent minerals of these basalts. They differ from the basalts of Cerro El Vigía in that they contain abundant large phenocrysts of feldspar, fewer and generally smaller phenocrysts of augite and olivine, and in the much more extensive alteration of the olivine to iddingsite (fig. 4*b*).

A sample from one of the San Lorenzo colossal heads (referred to as Monument 4 by Stirling, 1955, and now in Museo Jalapa) will suffice for detailed description. This is a porphyritic, intergranular, and in part diktytaxitic iddingsite-augite basalt. Phenocrysts of zoned calcic labradorite-sodic bytownite range in size from about 1.0 to 5.0 mm., most of them approximating 3.0 mm. in length. Together with the feldspar phenocrysts they constitute about 60 per cent of the total volume. Phenocrysts of pale green augite, mostly about 1.0 mm. in diameter but occasionally 3.0 mm. across, constitute approximately 20 per cent of the whole. Crystals of olivine, mostly between 0.2 and 0.5 mm. in diameter and rarely more than 1.0 mm. across, constitute about 6 per cent; all are replaced by deep russet iddingsite and hematite. Granules of magnetite, abundant needles of apatite, and flakes of hematite make up the remainder. An essentially similar basalt, used at La Venta in carving Altar 4, is illustrated in Figure 2b.

Monuments from La Venta

Ten of the La Venta monuments that we examined closely resemble in composition the basalt just described from one of the San Lorenzo giant heads, and it may well be that other La Venta monuments were made of basalt from the same source. We call attention now to monuments carved from other kinds of basalt.

The polygonal columns used so extensively at La Venta probably come, as noted earlier, from a rocky islet close to the shore west of Punta Roca Partida. They consist of dense, dark gray, intergranular olivine-augite basalt (fig. 2c). Except for a few small feldspars, olivine is the only mineral that can be recognized with the aid of a hand lens, and it makes up between 10 to 15 per cent of the total volume. A few olivine crystals measure 5.0 mm. in length; most measure between 0.5 and 1.0 mm., and many are only about 0.1 mm. long. Some crystals are altered along their margins to pale yellow-green antigorite or golden iddingsite, but most of them are perfectly fresh. Subhedral and roundish granules of gray-green diopsidic augite—few measuring as much as 0.5 mm. in maximum dimension and most measuring less than 0.1 mm.—occur between subparallel laths of labradorite, mostly 0.1 to 0.2 mm. long. Phenocrysts of plagioclase are notably lacking. Euhedral grains of magnetite, a few as much as 0.2 mm. in diameter, are scattered throughout, and some of the minute, triangular and polygonal spaces between the feldspars and augites are occupied by cristobalite.

Stela 2 is carved from a strongly porphyritic basalt that differs mainly in texture from the basalt used to make the San Lorenzo heads. It contains abundant phenocrysts of olivine, up to about 1.0 mm. across, all marginally altered to iddingsite, and of greenish augite, up to 3.0 mm. across. What makes it distinctive is the trachytoid texture of the dense matrix which consists of swarms of subparallel, closely packed microlites of andesine along with minute granules of augite and iron ore. In addition, the phenocrysts of labradorite are generally corroded and heavily charged with inclusions of ore and augite.

Stela 3, the largest of the La Venta stelae, and Stela C from Tres Zapotes are carved from essentially identical basalt.

Figure 5. "Stela" from La Venta site, now in the Parque Olmeca, Villahermosa, Tabasco.

A monument now in La Venta Park, Villahermosa, was discovered at the La Venta site in April 1959. It is 8 feet 5 inches high, 30 inches wide, and 18 inches thick (pl. 2d). Pellicer (1959) lists this as No. IX but does not illustrate it. He calls it a "stela of a bearded man hugging a monster." Figure 5 is a hasty sketch of the design on this slab, but it is heavily eroded and can be made out only in part. It is illustrated here because it seems possible that our record, imperfect though it may be, may be the best available for some time to come.

A second, unnumbered and heretofore not illustrated, La Venta monument, probably found in 1959, is a large boulder designated as No. 27 in the La Venta Park at Villahermosa but listed as No. 25 in the folded end map of Pellicer (1959). It is approximately circular, and measures 72 inches in diameter and 40 inches in thickness (pl. 2c). Axe-sharpening grooves occur in the upper surface, but it is otherwise unworked. We believe that this may be an example of a boulder brought to the site but never sculptured.

Both of the monuments mentioned above consist of basalt which is distinctive by reason of the comparative scarcity of olivine and the corresponding abundance of augite, the presence of many large phenocrysts of plagioclase—almost all of them with thin, clear rims and turbid cores—and an extremely dense, intergranular matrix. We have been unable to determine the source of this basalt, but almost certainly it lies in the Tuxtla Mountains and not in the highlands south of Villahermosa.

Notably different is the basalt of the La Venta monument called the "Abuelita" and designated as Monument 5. This is a dense, olivine-rich, intergranular basalt devoid of porphyritic feldspar. Approximately 20 per cent consists of olivine crystals, mostly between 0.5 and 1.0 mm. long but exceptionally 2.0 mm. long; some of these crystals are wholly replaced by iddingsite, but in most the iddingsite is restricted to the margins. Only a single phenocryst of augite was seen in thin section. The remainder of the basalt consists of slender microlites of labradorite—few of which exceed even 0.1 mm. in length—separated by equally small, subhedral granules of augite and iron ore. The lava resembles most closely that of the La Venta columns and Stela 3, the main difference being that the groundmass is finer grained. It was probably derived from a Quaternary flow in the Tuxtla Mountains.

MISCELLANEOUS NOTES ON OTHER MONUMENTS

The crudely rectangular "footing-blocks" in some of the La Venta structures consist mainly of augite-olivine basalts, rich in conspicous phenocrysts of feldspar and identical to many of the lava boulders of the Soteapan area and to the basalts of the Giant Heads of La Venta.

Thus far all of the monumental rocks that we have described, not only from La Venta but also from Tres Zapotes, San Lorenzo, and adjacent sites, are basalts of essentially the same mineralogical composition, distinguishable from each other only on account of variations in their content of olivine, augite, and plagioclase phenocrysts, their degrees of alteration, and their textures. There are, however, at least three monuments at La Venta which are carved from quite different lavas; namely, hornblende andesites probably derived from La Unión volcano or from the bed of the adjacent Río Osthuacán. These three sculptures are Monument 21 (Drucker, Heizer and Squier 1959:200-201) housed in the Museo at Villahermosa, Altar 7, and the remarkable monkey statue (Pellicer 1959: pl. 27; pl. 1*c* herein) housed in La Venta Park.

The andesite of Altar 7 is illustrated in Figure 2*a*. It is a vitrophyric hornblende-augite andesite. Approximately a quarter of the lava is made up of beautifully euhedral phenocrysts of hornblende, some of which measure 4.0 mm. in length. The mineral is pleochroic from pale yellow to deep brown in color, and most of the crystals are fringed with magnetite. Phenocrysts of pale green diopsidic augite, which measure between 1.0 and 3.0 mm. in length and constitute about 15 per cent of the bulk, are also euhedral. Microphenocrysts of labradorite, mostly less than 0.25 mm. long, constitute about 30 per cent, and euhedral grains of magnetite about 4 per cent. The remainder of the andesite is a matrix of dark glass and cryptofelsite containing many vesicles lines with minute spheroids of cristobalite. This lava is virtually identical with one of those collected from La Unión volcano.

The other five samples of andesite collected from La Unión volcano by us and those seen in the bed of Río Osthuacan differ from the foregoing only in having a pilotaxitic matrix composed of oligoclase microlites and interstitial cryptofelsite and in having more and larger phenocrysts of labradorite, some of which measure 3 mm. in length. Identical andesites occur as irregular blocks in an occupation deposit containing manos and metates which we noted on the north side of the La Venta site in 1962 during excavation of a pipeline trench.

In the course of our examination of stone monuments in the museums in Mexico City, Jalapa, and Villahermosa, we have noted a number of non-Olmec sculptures, or sculptures of Olmec type but of uncertain provenience, and we provide here some observations on the kinds of stones these are made of in the hope that the information may prove useful to other workers. Since we are not primarily interested in these sculptures, we did not make any effort to locate the sources of the rocks from which they were made.

1. Large seated figure in courtyard of Universidad Juarez de Tabasco, said to have been brought to Villahermosa from "el zona de La Venta." It is shown here in Plate 3*a*, *b*. The statue measures 1.4 m. across the base and is 1.735 m. high. It is carved from an extremely vesicular, pale gray andesite or basalt containing many large phenocrysts of augite, some of them half an inch long but containing only a few phenocrysts of feldspar. Accessory crystals of hornblende may be present.

2. The "Monumento Tortugas" or "Monumento Phallico" in the Museo Villahermosa seems, from a study with a hand lens, to be hornblende-rich, augite andesite devoid of large phenocrysts of feldspar. We hazard a guess that this type of lava, as well as that from which the large seated figure was carved, is more likely to have come from the highlands south of Villahermosa than from the Tuxtla Mountains.

3. Three sculptured monuments[8] in the Museo Villahermosa (pl. 4*a*-*c*) are said to have been found long ago in the Municipio de Huimanguillo, not far to the east of Villahermosa. A seated cross-legged figure (pl. 4*b*) is

carved from a highly vesicular augite-olivine basalt, the augite crystals measuring 2 to 3 mm. in diameter. The third sculpture (pl. 4c) is a "Janus" figure made of extremely vesicular pale gray intergranular augite-olivine basalt.

4. Monument fragment from three or four miles south of Soteapan. In 1962 we found, near the "road" leading from the highway to Soteapan, a flat, sculptured stone which we collected and left at the Pemex headquarters in Coatzacoalcos in the hope that it would be sent to the Museo Jalapa. It consists of an olivine-poor, augite-rich andesite different from any of the lavas used to make the monuments at San Lorenzo and La Venta. Phenocrysts of colorless augite, between 0.5 and 1.5 mm. long, make up about 10 per cent of the volume; phenocrysts of labradorite are more than twice as abundant, most of them measuring between 0.25 and 2.0 mm. in length. The minute, rounded grains of olivine scarcely exceed one per cent of the volume, and all are altered to a greenish-yellow montmorillonite-like clay. But the most distinctive feature of the lava is the fact that its dense matrix has a pilotaxitic rather than an intergranular texture, and consists of slender microlites of oligoclase, specks of iron ore and augite, and interstitial "cryptofelsite." The lava presumably came from a nearby, but unidentified, source in the Soteapan area.

5. Estela No. 1, El Viejon, Municipio Actopan: This monument, which is illustrated by Medellin (1960:pl. 9), consists of a different kind of lava from any we saw in the field and from any used in all other monuments that we examined. It was found about 30 kilometers north of Cempoala, a considerable distance outside the Olmec "heartland," and we describe it here since the data may be of interest to others. Medellin may be correct in assigning it to Olmec authorship, but we reserve opinion on this point. It is a pale gray, hornblende-biotite andesite or dacite. Phenocrysts of zoned plagioclase, mostly between 0.5 and 2.0 mm. long, constitute approximately 30 per cent of the volume. Their composition seems to range from sodic andesine to calcic oligoclase. Prisms of hornblende and flakes of biotite, mostly from 0.25 to 1.0 mm. in maximum dimension, are present in roughly equal amounts, together making up slightly less than 10 per cent of the whole. Both of these mafic minerals, but especially the hornblende, are converted largely to granular magnetite. The groundmass, which is cloudy with "kaolin" and hematite dust and splotched with calcite, consists of cryptofelsite and microfelsite, including a few small, irregular, clear patches of quartz. We think that this kind of lava is more likely to be of Tertiary age rather than Quaternary, and suppose that it came from some nearby source in the area lying between Veracruz and Jalapa.

6. "El Luchador Olmeca": The well known sculpture of a wrestler said to have been originally found by a native farmer on the Río Uxpanapa not far above its confluence with the Coatzacoalcos River (Corona 1962). Our notes on the stone are lost, but it is certain that the rock is distinctive and that no other monument seen by us in Veracruz or Tabasco is made of the same material. It may be an imported piece judging from its petrology, and its non-local origin is also suggested by the remarkable realism which is displayed. The piece is a puzzle, and some very special elucidation may be necessary to account for its existence.

7. Stela 1, "Piedra Labrada": This beautifully carved shaft was first described by Blom and La Farge (1926:41) and more recently by Melgarejo (1960). It bears calendrical glyphs indicating its date as 1483 A.D. Without microscopic study, we have tentatively identified the rock as an augite basalt or andesite, but do not know its source. It is, of course, much more recent than most of the sculptures described here.

APPENDIX I

Computation of the Weights of Some of the Larger Olmec Sculptured Pieces

Site	Monument	Weight (short tons)
La Venta	Stela 1	5.5
	Stela 2	10.5
	Stela 3	25.3
	Altar 1	36.5
	Altar 2	5.5
	Altar 3	13.7
	Altar 4	33.7
	Altar 5	18.6
	Altar 7	4.3
	Colossal Head No. 1	24.0
	Colossal Head No. 2	11.8
	Colossal Head No. 3	12.3
	Colossal Head No. 4	19.8
San Lorenzo	Colossal Head No. 1	25.3
	Colossal Head No. 2	20.0
	Colossal Head No. 3	9.4
	Colossal Head No. 4	6.0
	Colossal Head No. 5	11.6
Tres Zapotes	Colossal Head No. 1	7.8
	Colossal Head No. 2	8.5

NOTES

1. While certain rectangular, flat-topped stone sculptures from the sites of La Venta and San Lorenzo look like what are usually called "altars," there is not the slightest evidence that they were so employed. We retain the term as a purely descriptive one.

2. Some estimates of the amount of labor required to raise the earth structures and associated features at the La Venta site have been made earlier (Heizer 1960, 1961).

3. See Appendix I.

4. Compare our remarks with those written by Keiller, Piggott and Wallis (1941) in connection with their investigation of the sources of the stones used in making Neolithic stone axes in the British Isles: "At the outset...it was recognized that an examination of stone implements by their macroscopic characters alone would not suffice for their precise identification. Even if a freshly fractured surface is available, it is doubtful whether a correct identification can be made, except perhaps with such distinctive rocks as are found in the Presely Mountains and at Bwlch Mawr. It cannot be too strongly stressed that modern microscopical methods, applied to thin sections, form the only satisfactory criterion in the identification of [the stone of] implements."

5. Good bibliographies to publications dealing with these sculptured pieces can be found in Jones (1963), Garcia Payon (1963), and Smith (1963). Medellin (1960:map opp. p. 80) shows the location of Olmec and Olmec-related sites on the Gulf Coast of the states of Tabasco and Veracruz. A list of La Venta monuments can be found in Drucker, Heizer and Squier (1959:App. I).

6. One end of the islet has been lowered to about sea level, and from its appearance from the air this area looks like a quarry. We have thus far, in spite of several attempts, been unable to visit this locality.

7. There are other early dated sculptures from the area, such as the Tuxtla Statuette (Holmes 1907, 1916), but this is a small, portable object and not comparable to the much larger Stela C. If Stela C, now broken at each end, was originally three times the size of the presently known midsection, it would weigh about three-quarters of a ton.

8. One of these (pl. 4a) is highly vesicular and characterized by large augite phenocrysts 3 to 4 mm. in diameter and small olivines. It portrays a seated and cross-legged figure with the face tilted back to a nearly horizontal plane and rather resembles an Olmec sculpture described over thirty years ago by Nomland (1932), who believed that the figure represented a proboscidean. In 1962 we made a visit to the village of Moloacan on Arroyo Sonso to look for this sculpture but learned that it had been transported to Europe about 1932 or 1933 by a Swiss geologist named Tappolet(?) who was employed by the Aguila Oil Company.

EXPLANATION OF PLATES

Plate 1 a. Rectangular stone basin adorned with Pecten shells, from Tres Zapotes. Now in plaza at Santiago Tuxtla.

b. Rocky islet of columnar basalt west of Punta Roca Partida. Note probable quarry area in foreground.

c. Monument depicting monkey with the hands clasped behind its head, from La Venta site. Now in Parque Olmeca, Villahermosa, Tabasco.

Plate 2 a,b. Small hunched jaguar figure from Cuenca de Coatzacoalcos. Now in Parque Olmeca, Villahermosa, Tabasco.

c. Large boulder, approximately circular, measuring 72 inches in diameter and 40 inches in thickness, from La Venta. Same location as a.

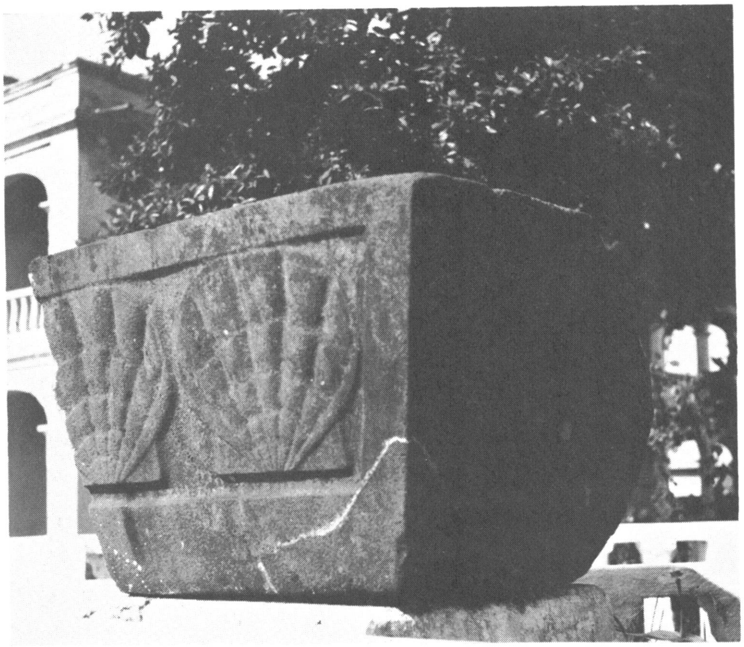
d. Monument discovered after 1955 at La Venta. It is 8 feet 5 inches high, 30 inches wide, and 18 inches thick. Pellicer (1959) calls this a "stela of a bearded man hugging a monster." See Figure 5 (p. 19) for sketch of design on this slab.

Plate 3 a,b. Large seated figure carved from vesicular, pale gray andesite, measuring 1.4 m. across the base and 1.735 m. high. Said to have been brought to Villahermosa from La Venta in 1905 by Don Policarpo Valenzuela. Now in Universidad Juarez de Tabasco. Photos supplied by courtesy of Dr. Carlos Sebastian Hernandez, Conservador del Museo Regional de Tabasco.

Plate 4 a. Sculptured figure, highly vesicular, probably from the Municipio de Huimanguillo, not far to the east of Villahermosa. Now in the Museo Villahermosa.

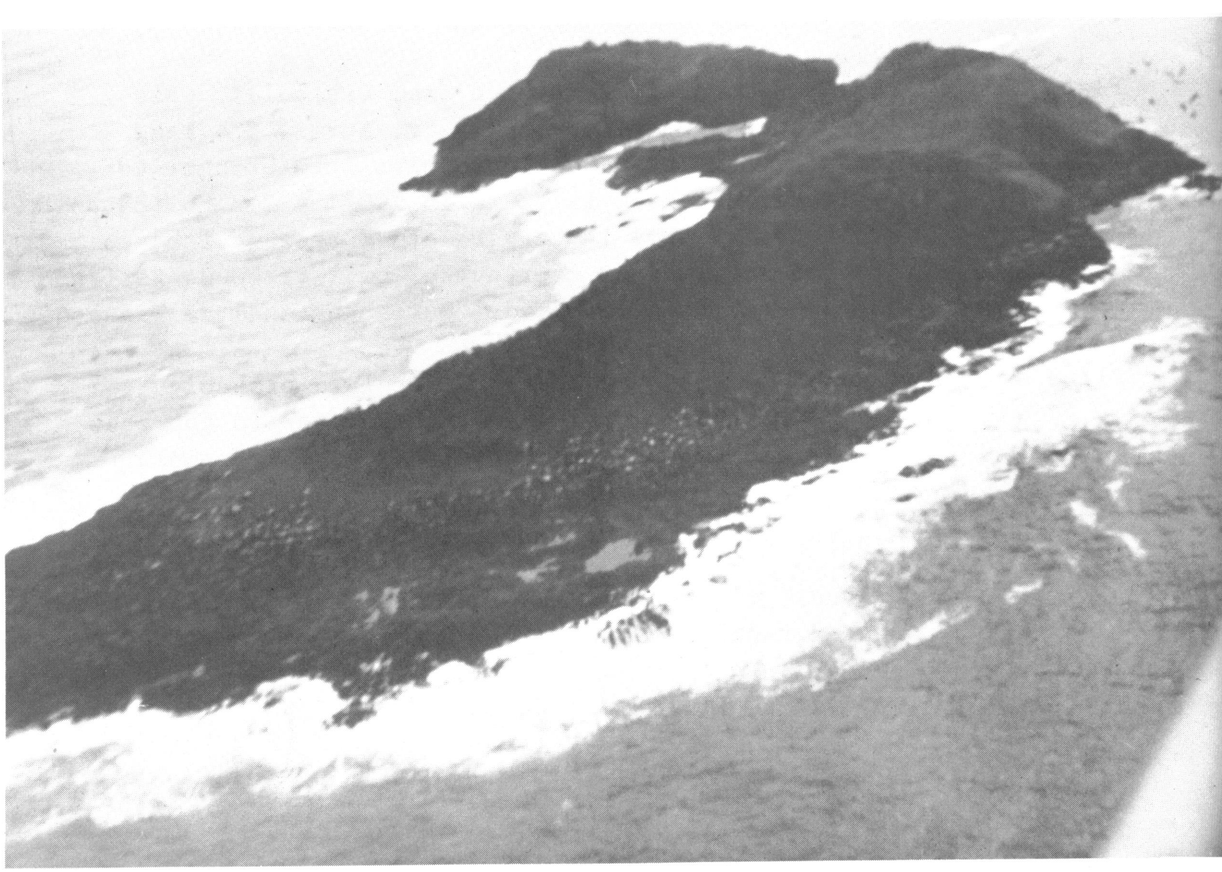
b. A seated, cross-legged figure carved from highly vesicular augite-olivine basalt. Same location as a.

c. "Janus" figure made of extremely vesicular pale gray intergranular augite-olivine basalt. Same location as a.



a

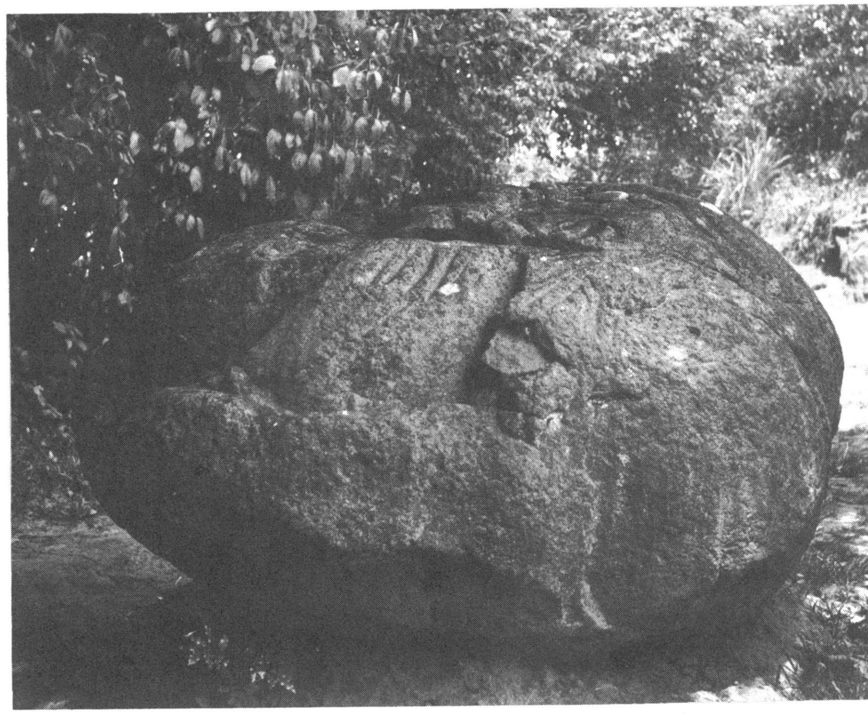
c



b

Plate 1

a



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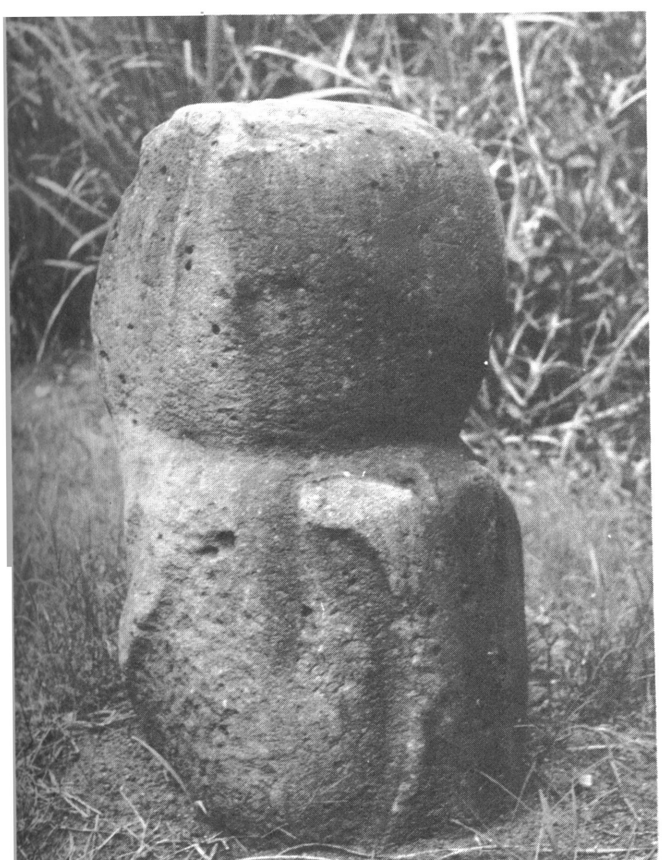

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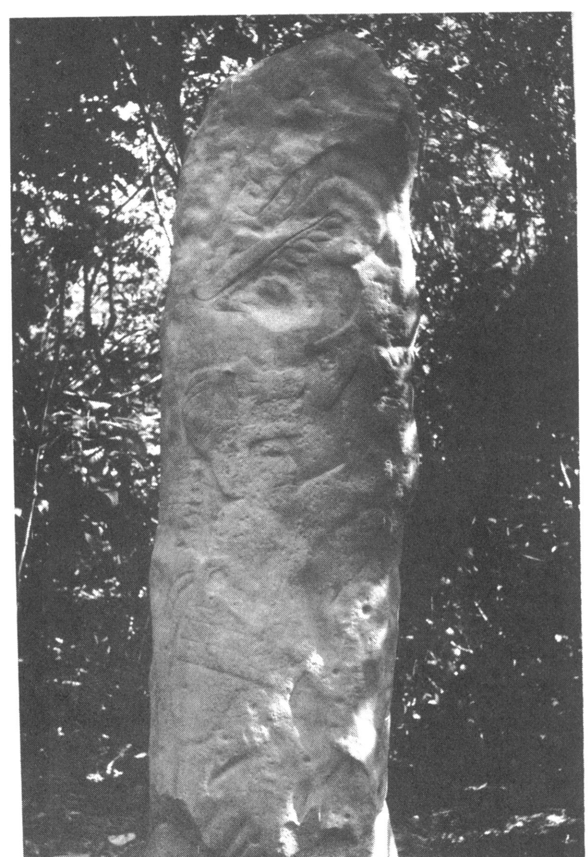
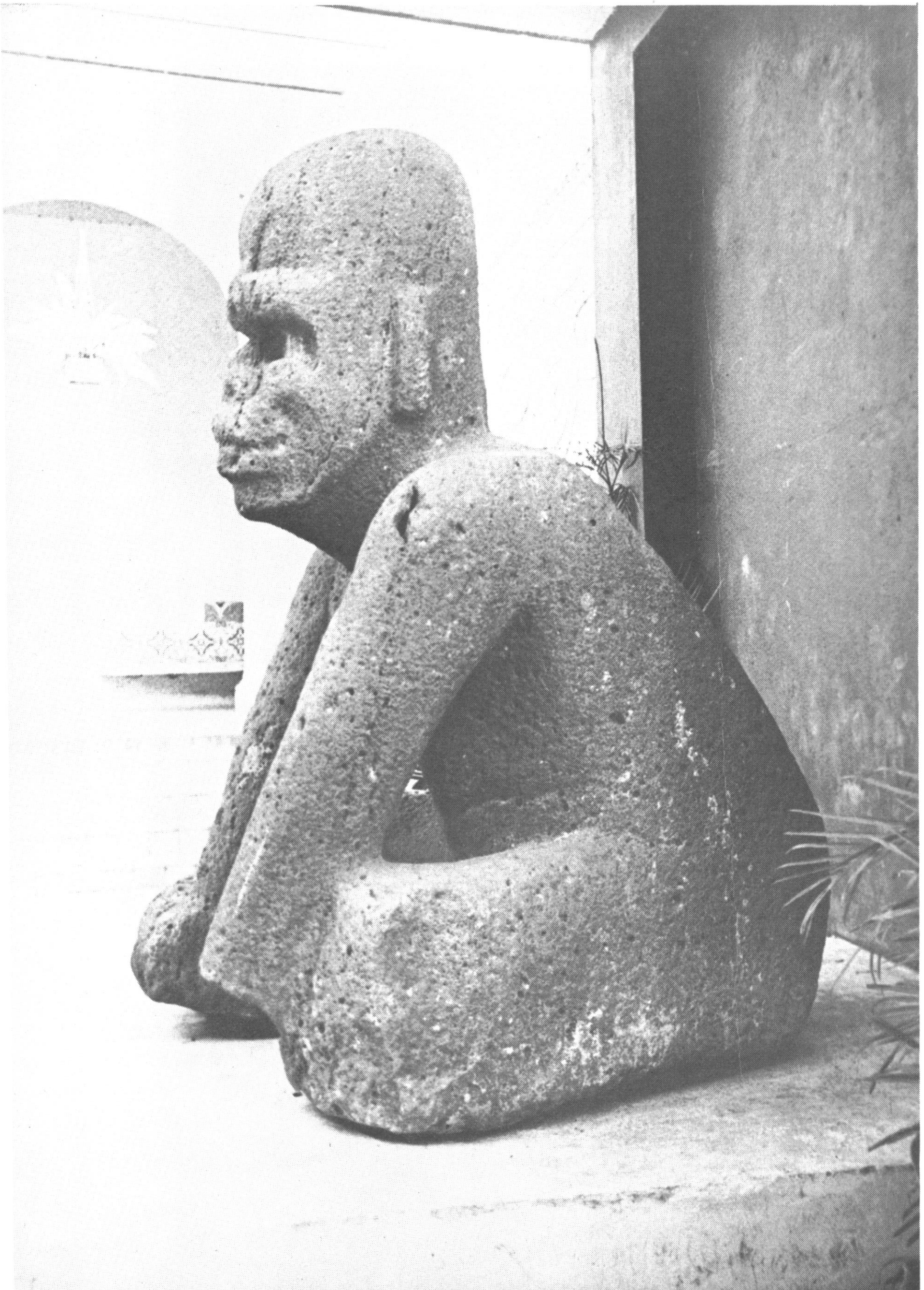
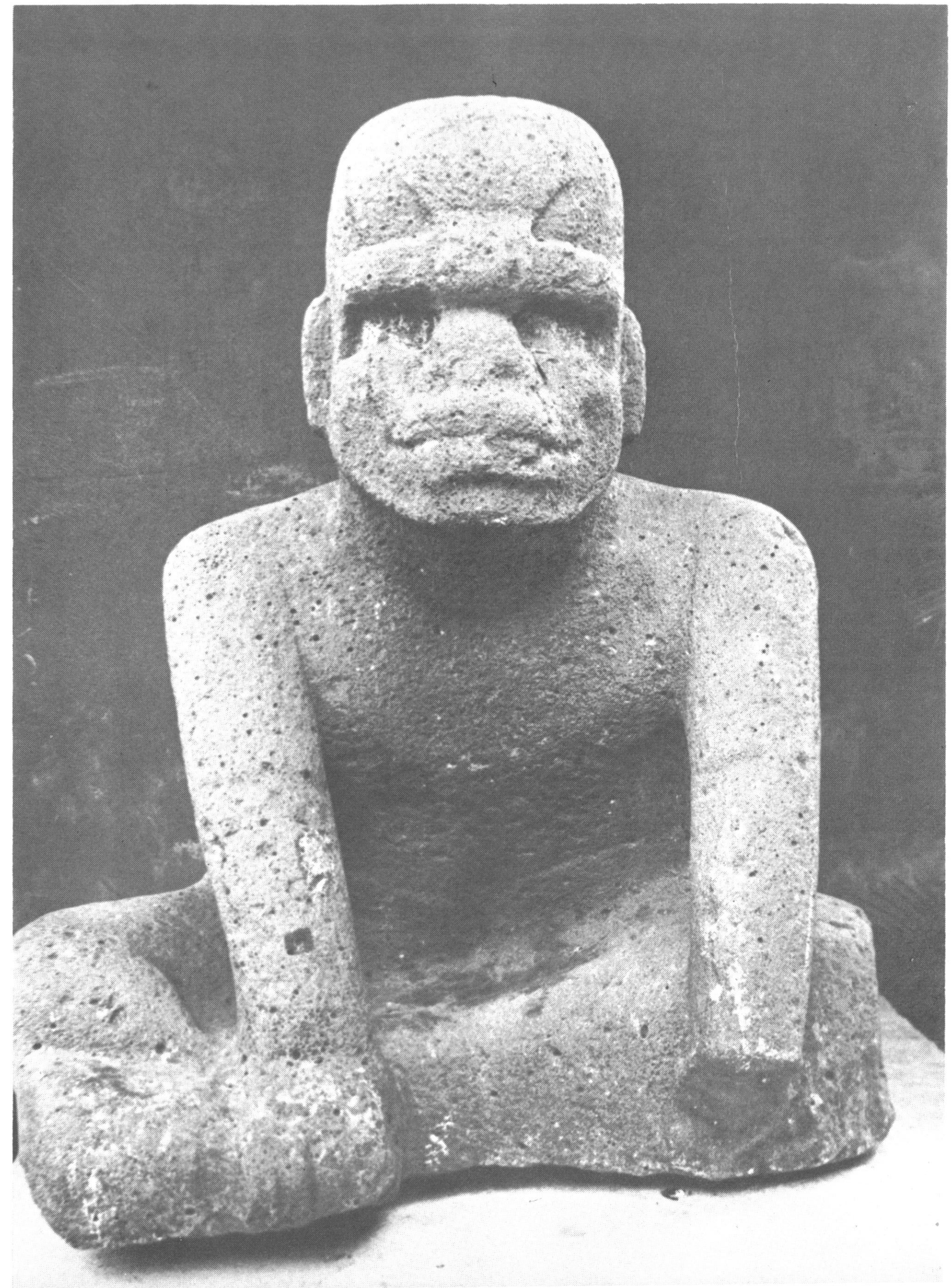


d

Plate 2



a



b

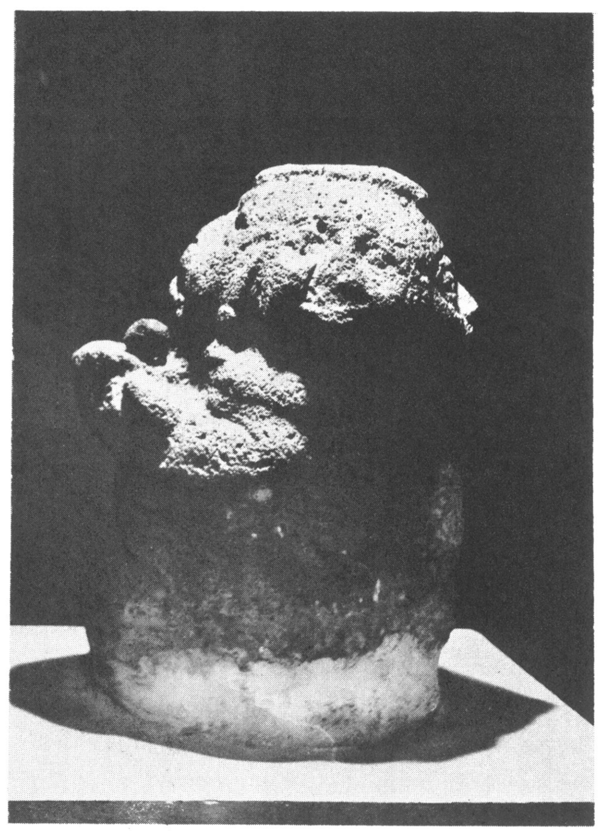
Plate 3

11

a

10

b



c

Plate 4

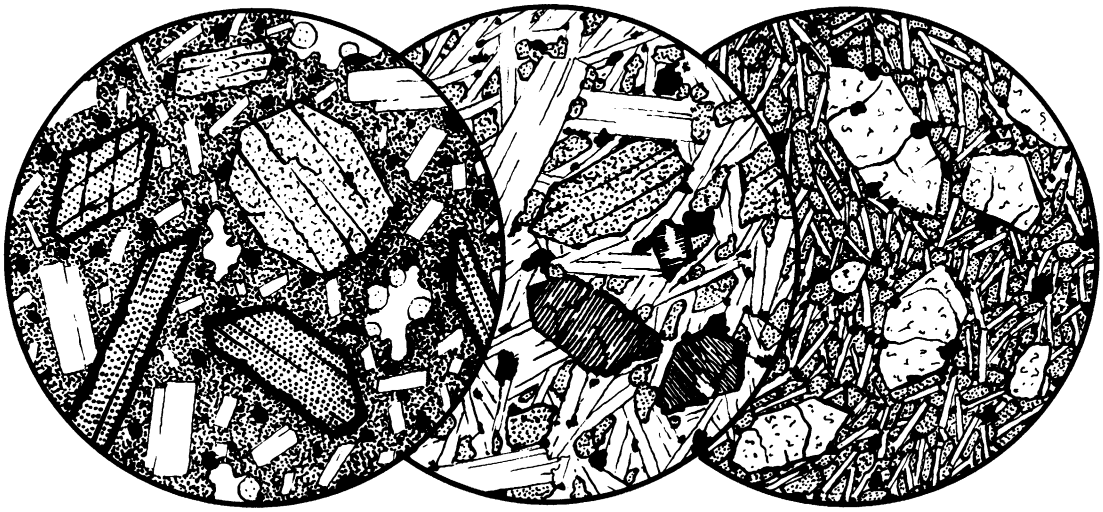


Figure 2. Lavas used in some of the monuments at La Venta. Diameter of each field 2.5 mm.

_a_. Hornblende-augite andesite of Altar 7. Spheroids of cristobalite line the vesicles.

_b_. Olivine-augite basalt of Altar 4. Olivine largely replaced by russet iddingsite.

_c_. Olivine-augite intergranular basalt from one of the columns.

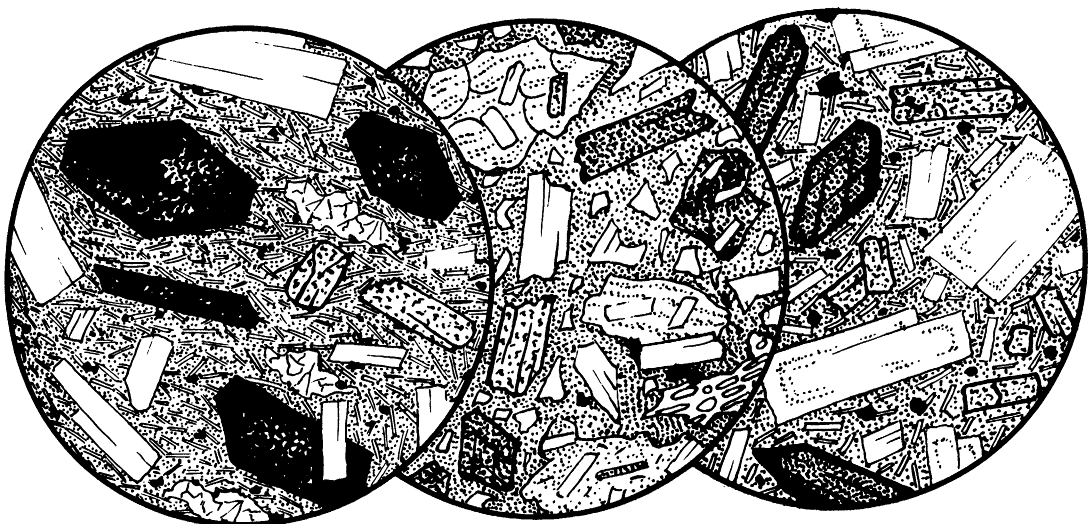


Figure 3. Andesites used in some of the monuments at Cerro de las Mesas. Diameter of each field 2.5 mm.

a. Oxyhornblende-hypersthene andesite with tridymite-filled pores, Stela 9.

b. Andesitic crystal-vitric-lithic tuff, Stela 3. Chips of vitrophyric andesite, one of them pumiceous, and broken crystals of dark green hornblende, paler hypersthene, and colorless plagioclase in a matrix of glass-dust.

c. Oxyhornblende-hypersthene andesite, Monument 6. Brown hornblendes rimmed with magnetite; hypersthene and a little augite; phenocrysts of zoned labradorite-bytownite, and microliths of oligoclase in a matrix of 'cryptofelsite.'

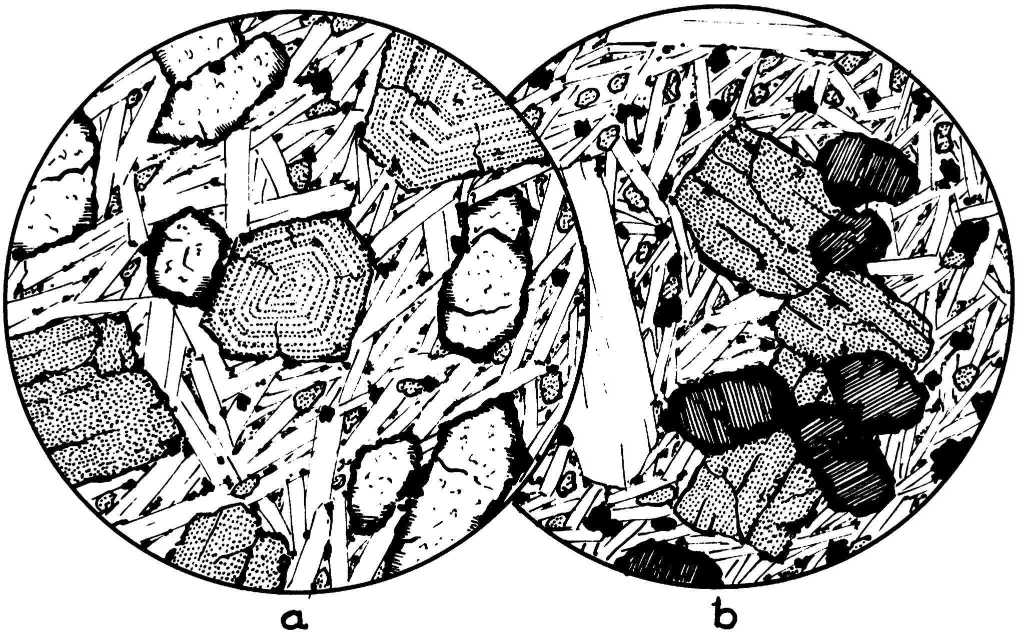


Figure 4. Basalts from Cerro El Vigía (a) and from one of the San Lorenzo giant heads, Monument 4, Museo Jalapa (b). Diameter of each field 3 mm.

a. Zoned phenocrysts of augite, and phenocrysts of olivine with only slight marginal alteration to magnetite and iddingsite.

b. Olivine phenocrysts completely altered to deep russet iddingsite; augite phenocryst unzoned; note also parts of two large plagioclase phenocrysts.

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AAnt	American Antiquity
BAE-B	Bureau of American Ethnology, Bulletin
KAS-P	Kroeber Anthropological Society, Papers

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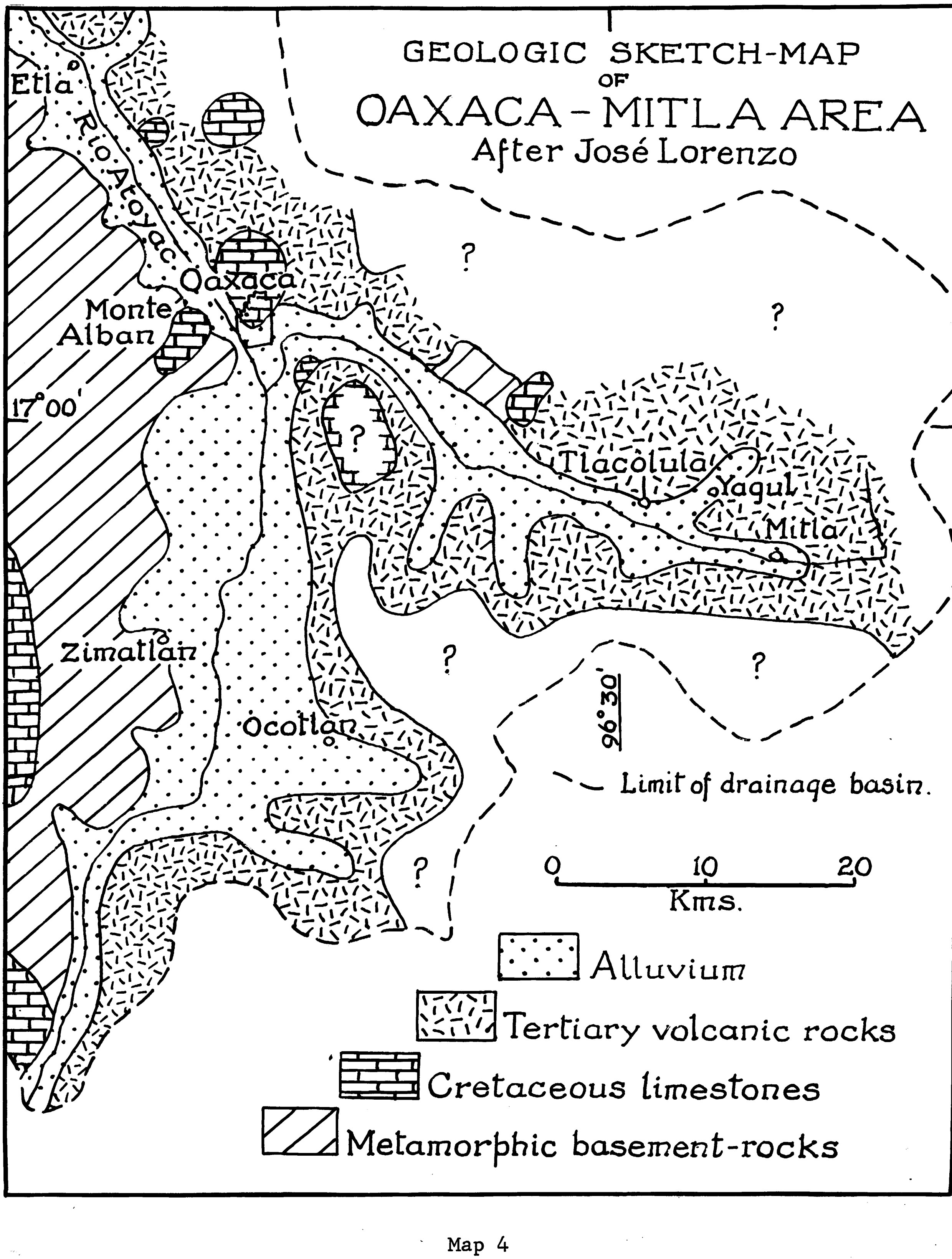
GEOLOGIC SKETCH-MAP
OF
OAXACA - MITLA AREA
After José Lorenzo
Etla
Rio Atoyac
Oaxaca
Monte Alban
17°00'
Zimatlan
Ocotlan
Tlacolula
Yagul
Mitla
96°30'
Limit of drainage basin.
0
10
20
Kms.
Alluvium
Tertiary volcanic rocks
Cretaceous limestones
Metamorphic basement-rocks

Map 4

GEOLOGICAL NOTES ON THE RUINS OF MITLA AND OTHER OAXACAN SITES, MEXICO

Howel Williams and Robert F. Heizer

W. H. Holmes (1897:229) pointed out long ago that "Mitla is what it is largely because of the presence of inexhaustible supplies of superb and easily worked building stone." In great measure it is the geological setting of Mitla that has made possible the marvellous architectural forms and the beautiful mural mosaics with their intricate geometric designs for which the ruins are famous. Elaborate stone work of this kind would have been, for all practical purposes, impossible at the neighboring site of Monte Alban because the materials available there were mostly limestones, quite intractable and wholly unsuited to the fashioning of elaborate mosaics. At Mitla, however, there was not only abundant stone suitable for construction and sculpture, but also a copious supply of other stones ideal for use as cutting, scraping, polishing, and hammering tools. None can doubt that this fortunate combination accounts to a considerable extent for the excellence and beauty of the architecture and stone work at Mitla. Clearly, however, other important factors were involved, for at the neighboring site of Yagul the buildings and sculpture are decidedly inferior even though most of the materials for construction are similar.

The stone used at Mitla for facing walls, for lintels and door jambs, pillars, columns, and mosaics (pl. 5a, c) was referred to by Holmes as "a variety of volcanic lava known as trachyte." Any other competent geologist of his day would have said the same. The stone is, however, a kind of volcanic tuff, laid down probably during Middle Tertiary times by glowing avalanches. All tuffs produced by glowing avalances, no matter whether erupted from fissures or cones, are nowadays called ash flow tuffs or ignimbrites. Ignimbrites were used extensively as building stones not only at Mitla but in many parts of Latin America during Spanish colonial days, and are still being used extensively both there and in many other regions of the world. Because most archaeologists are probably not familiar with their nature and origin, our account of the particular ignimbrites used at Mitla is prefaced by an account of ignimbrites in general.

In 1912 devastating eruptions took place in the Valley of Ten Thousand Smokes in Alaska. Foaming magma rose to the surface through swarms of narrow fissures near the head of the valley. The effervescing, intensely hot liquid burst at once into incandescent spray, droplets, and bombs, all giving off large volumes of gas. The mass of ejecta did not rise high into the air but swept along the ground, rushing down the valley at incredible speeds as glowing, turbulent avalanches of ash and pumice. No less than 2.5 cubic miles of material were thus expelled, burying more than 40 square miles of the valley, in places to a depth of 700 feet. Indeed so much material was expelled that the central pipe of the adjacent volcano, Mount Katmai, was drained, leaving the summit without support. The mountaintop therefore collapsed, leaving in its place a vast caldera.

No one witnessed these Alaskan eruptions at close quarters; in fact it was not until four years later that Robert Griggs visited the region and was amazed when he discovered that what had been a verdant valley was now blanketed with hot ash and barren of all vegetation. Myriads of steam plumes rose from fumaroles in the ash deposits, and some of the fumaroles were still so hot that they ignited wood thrust into them. The basal and surficial parts of the ash deposits cooled quickly, but the thick inner parts remained extremely hot for many years. For that reason the constituent particles of volcanic glass in the interior of the deposits retained their plasticity for a long time so that they were flattened by the overlying load and were firmly annealed to each other. The larger pumiceous lapilli and bombs were also flattened into irregular discs. No wonder, therefore, that the streakily banded, welded tuffs look deceptively like many banded lava flows.

Subsequent studies have amply shown that similar glowing avalanches of ash and pumice have been erupted in many parts of the world, in all geological periods, often in colossal volumes, and usually from fissures rather than from the craters of cones. Vast areas formerly thought to be covered by lava flows are now known to be covered by ignimbrites. During Cenozoic times, for example, no less than 80,000 square miles of the Great Basin of Utah and Nevada were buried by ignimbrites, locally to a depth of 8,000 feet; more than 10,000 square miles of the North Island of New Zealand were buried in similar fashion; as were extensive areas in the plateau of Mexico; in Central America; and on the flanks of the Andes in Chile and Peru. In all these places the ignimbrites have long provided abundant, easily worked and durable materials for building and sculpture.

It follows from what has been said that within any given sheet of ignimbrite—the product of a single avalanche—there is generally a pronounced vertical variation in the degree of induration. The quickly cooled top and bottom parts usually consist of loose, incoherent ash, unsuitable for building stone; the inner parts, on the contrary, because they remained hot for a long time, tend to be firmly compacted by annealing and welding of the fine particles of plastic glass, by crystallization (devitrification) and by deposition in pore spaces of silica minerals (tridymite and cristobalite) from fumarolic gases. In some sheets of ignimbrite, generally two-thirds to three-quarters of the distance from the top, annealing of the glass particles and flattening of the pumice lumps have progressed so far as to form extremely dense, black banded tuffs which are almost indistinguishable from finely banded flows of obsidian.

Some ignimbrites are strongly welded almost from top to bottom. Glowing avalanches may follow each other in such quick succession that the deposits of one are still partly incandescent when buried by the next, in which case no loose, quickly chilled ash is present at the bottom of the second sheet. Other ignimbrites are only moderately indurated and show litte vertical variation. Among these are the so-called sillars of Peru, the induration of which was caused mainly by crystallization of the glass and deposition of silica-minerals from hot gases. Sillars are particularly easy to cut and trim, and tend to harden as they dry. Intensely welded glassy tuffs, on the other hand, are difficult to fashion on account of their brittleness. Many ignimbrites, especially the firmly welded ones, develop beautiful columnar structures as they cool and solidify, and even sillars usually develop well-marked joints perpendicular to their tops and bottoms. It is not surprising, therefore, that the indurated parts of ignimbrite sheets commonly form cliffs which overhang the loosely consolidated basal parts. Large, plane-faced slabs and columns of indurated tuff break from the cliffs to accumulate below as talus, providing convenient materials for construction; moreover, the natural undercutting of the incoherent ash and the vertical jointing of the overlying tuff greatly facilitate quarrying operations.

Some of the lithological variations within ignimbrites are summarized in Figure 6a and b.

THE MITLA IGNIMBRITES

The southern end of the Valley of Oaxaca and much of the Valley of Mitla are bordered by mountains eroded in a thick succession of ignimbrites; to the north, on the contrary, the dominant volcanic rocks are flows of andesitic lava. Detailed studies would almost certainly reveal slight petrographic variations between the various sheets of ignimbrite, but our preliminary observations suggest that the principal ones by far are composed of biotite, rhyolite, or rhyodacite. They consist essentially of crowds of broken crystals—mostly of plagioclase feldspar and quartz, with a few of sanidine—accompanied by many flakes of brown biotite and a few prisms of green hornblende. In some ignimbrites these minerals are embedded in a matrix of ash particles and bits of pumice that are still glassy; in most, however, the once glassy matrix has been devitrified to micro- and crypto-felsite. Many ignimbrites are heavily loaded with small, angular fragments of older ignimbrites and of rhyolitic or rhyodacitic lava; others are almost devoid of such fragments. Debris of this kind was incorporated in the glowing avalanches either as they rose from the feeding fissures or during their swift passage over the surface. Careful microscopic examination would perhaps serve to identify the location of some of the particular ignimbrites quarried by the builders of Mitla, but our stay was too brief to permit us to locate any sources additional to those reported by Holmes.

Almost all of the worked stones at Mitla are of the sillar-type of ignimbrite; very few are of the intensely welded type. Noteworthy is the fact that many of the large lintel stones are of approximately the same length, that is to say about 3.8 meters; a few measure 4.5 meters in length and the largest measure about 6 meters (pl. 5b). It may well be that the length of these lintel stones was determined only in part by architectural requirements and mainly by the thickness of the more indurated portions of the sillars at the quarry sites. The following table gives the dimensions of some lintels at Mitla.

TABLE 1

Dimensions, Volumes, and Weights of Some Lintels at Mitla

	Length (m.)	Width (m.)	Thickness (m.)	Volume (m^3)	Weight (metric tons)
1.	3.82	1.00	0.62	2.37	5.45
2.	3.76	1.10	0.74	3.06	7.04
3.	4.74	1.62	1.00	7.68	17.70
4.	4.60	1.62	1.00	7.45	17.10
5.	6.00	1.59	1.17	11.23	25.80
6.	5.65	1.59	1.17	10.51	24.20
7.	4.46	1.00	1.55	6.91	15.90
8.	3.90	1.08	0.80	3.37	7.80
9.	4.42	1.17	0.80	4.15	9.50
10.	3.96	1.10	0.80	3.48	8.00

We visited the nearest quarry site to Mitla and saw the partially hewn block of sillar which Holmes (1897:282) described and illustrated. It lies at the base of an overhanging cliff on the north side of the valley, about two kilometers east of the ruins. This block, which measures a minimum of 4.0 m. in length, 1.15 m. in width, and 1.5 m. in thickness, clearly reveals some of the methods of the Mitla quarrymen.

We also saw crudely worked rectangular blocks along and at the base of a ridge which projects into the valley about four kilometers east of Mitla, close to the trail used as a short cut to Santo Domingo and San Lorenzo. These blocks measure 1.9 x 2.23 x 0.6 m., and 1.8 x 2.1 x 0.4 m. (pl. 6a, b). Worked blocks are also to be seen, so we were told, still farther east, at much higher elevations, in a quarry where stone for a nearby cruciform tomb was extracted.

Holmes described and illustrated large blocks of ignimbrite at a quarry site nearly 300 meters above Mitla and at least 10 kilometers to the north. Some of the blocks at this site were already detached while others had been left partly cut out or only outlined. The larger blocks, Holmes said, measure "12 feet or more in length by 5 or 6 wide, and from 2½ to 3 feet thick" and they weigh perhaps 15 short tons, which is about the weight of the heaviest lintel stones at Mitla (cf. pl. 6c, d). It was Holmes' opinion that the quarrymen probably planned to haul the blocks to Mitla by a roundabout route, following gentle slopes rather than dragging them directly down the mountainsides. According to Holmes, there are at Mitla "upwards of fifty lintel stones, ranging from 10 to 20 feet in length and from 2 to 4½ feet in each of the other dimensions, their weight varying from 10 to 15 [short] tons." Some of the cylindrical columns, which were used mainly to support roof timbers in the wider chambers, measure about 11 feet above ground and perhaps 15 or 16 feet in full length; their diameters diminish as they rise from the floor where they measure 30 or 36 inches to 20 or 24 inches at the top; their weights approximate 6 to 8 tons.

The Mitla tuff is fairly durable, but shafts as long as 6 meters, if dragged over uneven ground, might snap in two. It seems very probable, therefore, that these large slabs were lashed to rigid wooden sledges whose runners would absorb the strains imposed by the irregularities of the ground surface so that the block itself was not subjected to undue strain. No such sledges, nor pictured representations of them, have ever been found, but there is good evidence at Mitla that solid wooden beams 9 inches square and over 12 feet long were used for rafters in some of the buildings. Timbers of this size would have served very well for sledge construction.

Using Barber's formula (1900:41; cf. Heizer and Williams 1963:97), the largest lintel at Mitla, which weighs about 25 metric tons (55,000 pounds), could have been dragged on a sledge with ropes by about 366 men.

No certain evidence of the use of ropes has been found at Mitla, but we believe that they were almost certainly used as aids in transporting the multiton ignimbrite blocks from the quarries to the site. Today there is a large amount of maguey grown locally, and according to what we heard, larger amounts were grown here in earlier times. In the earth fillings of the Mitlan walls are large numbers of "push-planes" or "scraper-planes" which show wear on the sharp basal edge. Holmes (1897: 286, pl. XLII) described and illustrated these, and we provide additional illustrations (pl. 7) of this type of implements, which show evidence of having been used to work some relatively soft material. We suggest that these tools served to express the pulp from the pounded maguey leaf during the process of fiber extraction carried out in the same general fashion as described by Lothrop (1929) for Guatemala, except that in Guatemala the handled wooden scraper rather than the stone push-plane was used. The large numbers of scraper-planes at Mitla can therefore be accounted for by assuming that large amounts of rope were made here for use in the construction activities.

Stone Tools

Holmes thought that the tools—hammerstones, picks, flakes, and scrapers—used at Mitla were made from "roundish masses or waterworn boulders of the harder varieties of volcanic lava" and from a "coarse, yellowish striped flint or flinty quartzite." These materials, he said, are found "in great numbers in the adobe mortar used in hearting the walls and pyramids of the great buildings at Mitla," and he correctly surmised that they must occur in the neighborhood "in bodies sufficient to be quarried or in surface masses so numerous as to be collected in considerable quantities." He found abundant flaked stones as shop refuse on the spur of the Fortified Hill about two kilometers west of Mitla. Here, he said, the "ground was filled with broken flint, generally of a grayish hue, and wholly distinct from the yellowish flinty rock worked elsewhere." Finding only a single imperfect hammerstone, he concluded that only blades were made at this locality.

Our observations suggest that almost all of the hammerstones and picks used at Mitla were made from firmly indurated ignimbrites, fragments of which were available in vast quantities on the sides of the valley and in the stream beds to the east. Most of the flakes and scrapers, on the other hand, were made from silicified tuffs and tuffaceous sediments, the principal, though probably not the sole, source of which was along the base of the Fortified Hill.

The Fortified Hill itself is composed of a series of cliff-forming ignimbrites which dip northward at low angles. Near the base of the hill, on the southern and eastern sides, these massive ignimbrites are underlain by a greenish, altered ignimbrite which is interbedded with much thicker layers of well stratified, whitish tuffs and tuffaceous muds and silts. These very fine-grained, airborne and fluviatile deposits are extensively silicified and in many places are veined and replaced by chalcedony. Close to the spring near the western base of the hill a few steeply dipping and vertical veins of chalcedony, up to about 30 cm. thick, cut the thinly bedded tuffs; not far away thin lenses of chalcedony conform to the bedding of the tuffs.

Silicification of the tuffs and tuffaceous sediments as well as the development of greenish clay (montmorillonite?) in the interbedded ignimbrite were caused by moving groundwaters enriched in silica and other constituents through alteration of the overlying ignimbrites. That is why greenish ignimbrites are invariably found close to the floors of the valleys of Mitla and Oaxaca. The ignimbrite used in construction of the cathedral and several churches in Oaxaca comes from quarries near the floor of the valley, a short distance southeast of the city. Only rarely are the ignimbrites on the valley sides silicified or discolored by alteration; it was the older, fine-grained airborne and waterlaid tuffs and tuffaceous sediments which were especially susceptible to such changes, particularly where groundwater was plentiful.

The gently undulating slopes adjoining the Fortified Hill are thickly strewn with angular fragments of chalcedonic flint. To the east of the spring, as Holmes noted, the flints are almost all pale to dark gray in color; to the west, however, there are abundant yellow, brown, and orange colored flints similar to those present in profusion among the ruins of Mitla. In our opinion this was probably the main source for the scrapers and flakes. The notable scarcity of chalcedonic debris in the bed of Río Mitla to the east of the ruins indicates that very little flint came from the upper parts of the valley, where most of the hammerstones and picks were obtained. Holmes suggested (1897:287) that the flint outcrop and workshop at the base of the Fortified Hill "was occupied by a people distinct from the builders of Mitla, or possibly by the Mitlan stock at an earlier period in its history." This statement is an interesting one in that it illustrates Holmes' keen awareness of assessing archaeological situations and his willingness to propose time differences in American prehistory at a time when his colleagues in archaeology were almost completely unaware of even the possibility of making temporal distinctions between different sites.

Holmes' geological training no doubt was responsible for his ideas on this matter. We did not make any special study of this workshop area and do not have any opinion on whether it may be older than the Mitla site proper.

The ignimbrites on the valley sides near Mitla vary, as we have pointed out, from brittle, dense, glassy types to soft sillar types; hence they provided materials not only for construction and sculpture but also for a wide variety of other uses, such as hammering, picking, scouring, and polishing. But for cutting and scraping, use was made of the silicified tuffs, especially of those completely replaced by chalcedony. It was this juxtaposition of abundant materials for tools of many kinds with abundant and easily worked building stones that particularly favored the peoples of Mitla.[1] Perhaps they first worked the soft sillars along and close to the valley floor, and then went farther afield in search of more strongly indurated and crudely columnar sillars from which they fashioned their huge lintels and jambs. Why else would they have gone ten kilometers to the north, climbing 300 meters, to quarry the slabs described by Holmes?

Use of Andesite

Our impression is that along the floor of the valley between Mitla and Oaxaca and in the adjacent mountains the ignimbrites are generally underlain by andesitic lavas and thinly bedded tuffs and tuffaceous sediments. Apart from the beautiful green ignimbrite in the roadside quarries near Oaxaca, most of the volcanic rocks extending along both sides of the valley between the city and Tlacolula are andesites. As far as we know no andesites are exposed close to Mitla and none seem to have been carried there for construction. At Yagul, on the other hand, waterworn boulders of andesite are about as common as those of ignimbrite.

We saw no ignimbrites at the Monte Alban site, and only a little andesite, almost the sole building stone there being local limestone. In a ruin group east-northeast of the principal group of buildings designated as Tumba 105 by Caso (1938:83-95, Plano No. 18) there is a doorway built of slabs of purplish, porphyritic, and vesicular pyroxene andesite, one of which measures approximately 4.2 x 1.6 x 0.6 m. and weighs more than four metric tons (pl. 5d). These andesite slabs were probably transported at least ten kilometers from the high range that separates Tlacolula from Ocotlan (map 4).

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[1] A similar situation exists at the site of Copán and we will report separately on this site.

Sources of Lime

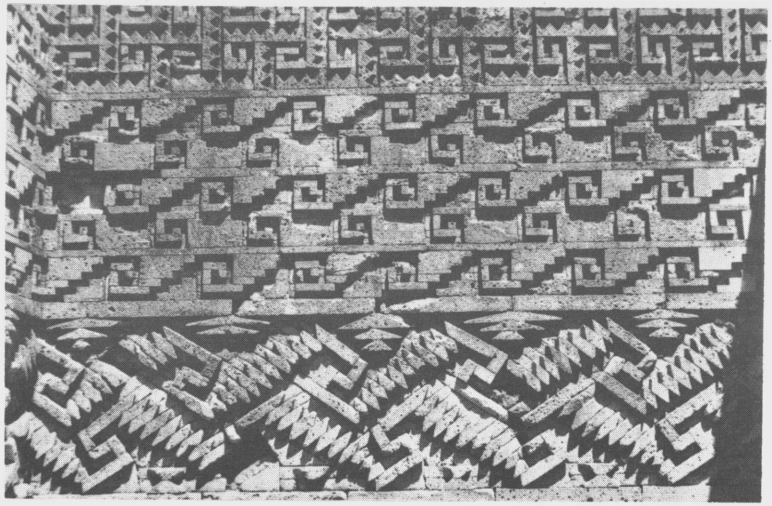
Holmes said that the source for the lime used at Mitla for plaster, cement, and mortar was unknown. The ignimbrite blocks were so carefully cut and precisely fitted that little mortar was required and perhaps the small amount of lime that was needed came from the outcrops of Cretaceous limestone on the north side of the valley, about 20 kilometers northwest of Mitla, although some may have been obtained to the east, near Santo Domingo, where deposits of travertine occur.

DENSITIES OF CERTAIN ROCKS

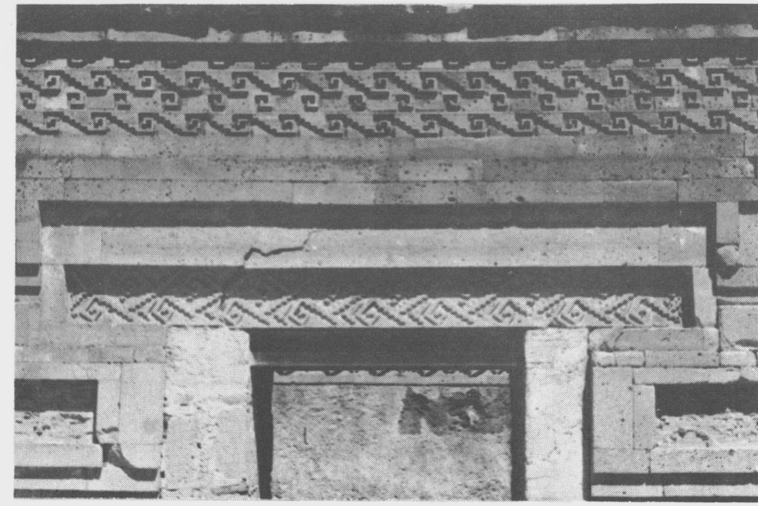
Because the information may be useful to others, we give here our determination of densities of certain rocks at Mitla and Monte Albán.

1. White, loosely coherent, sillar-type ignimbrite, 2.01
2. White, loosely coherent, sillar-type ignimbrite, 1.80
3. Dense, firmly welded ignimbrite, 2.46

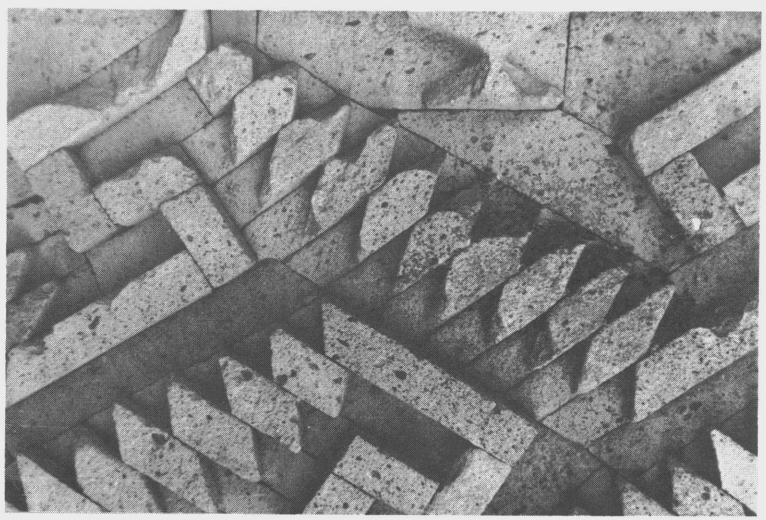
In general it can be said that the Mitla lintels and jambs are composed of moderately welded ignimbrite and range in density from 2.20 to 2.30. At Monte Albán the andesite used for jambs and the lintel at Tumba 105 has a density of 2.38. This is a relatively low value and is probably explainable as due to the microporous and minutely vesicular character of the lava.



a. Detail of "mosaic" facade at Mitla



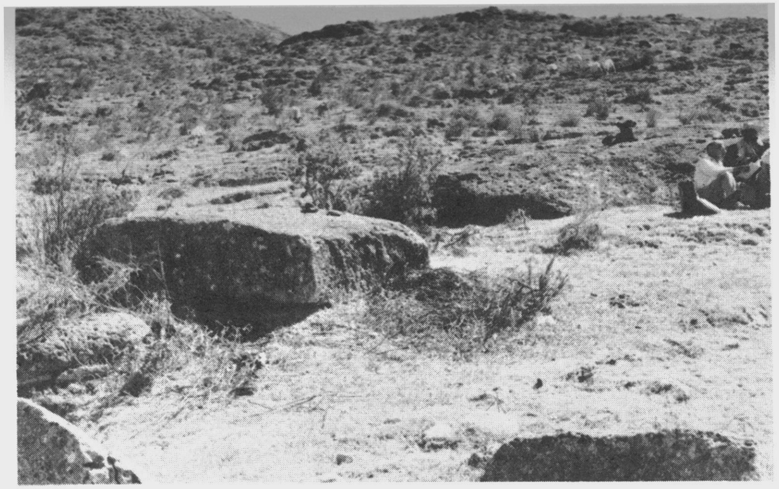
b. Strain-cracked lintel in Quadrangle of the Grecques, Mitla



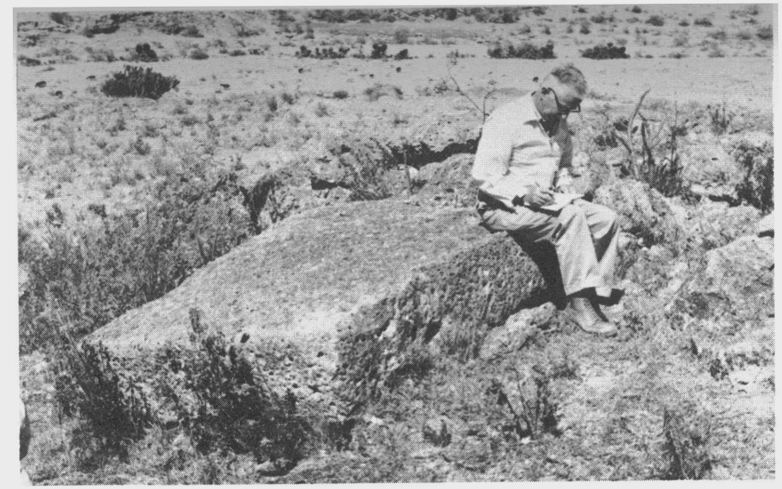
c. Detail of "mosaic" at Mitla (cf. Holmes 1897, pl. XXX A-B

d. Jambs and lintel, Tumba 105, Monte Albán

Plate 5



a. Abandoned building blocks along trail about 4 km. east of Mitla



b. Same as a

c. Large fallen lintel in front of Hall of Columns (No. 2 in Table 1), weight ca. 7 metric tons

d. Large lintel of ignimbrite at Mitla

Plate 6

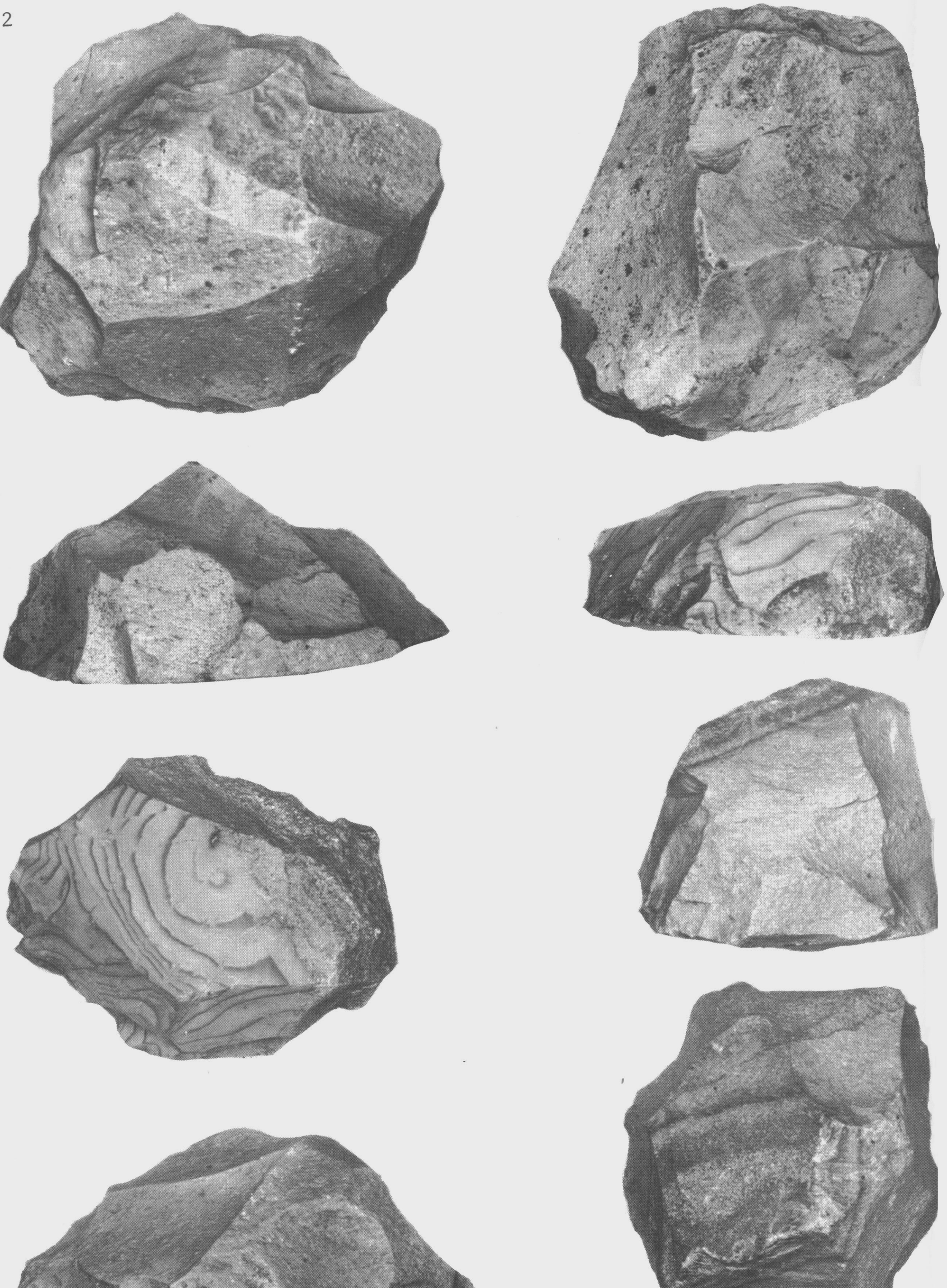


Plate 7

Scraper-planes from Mitla (actual size)

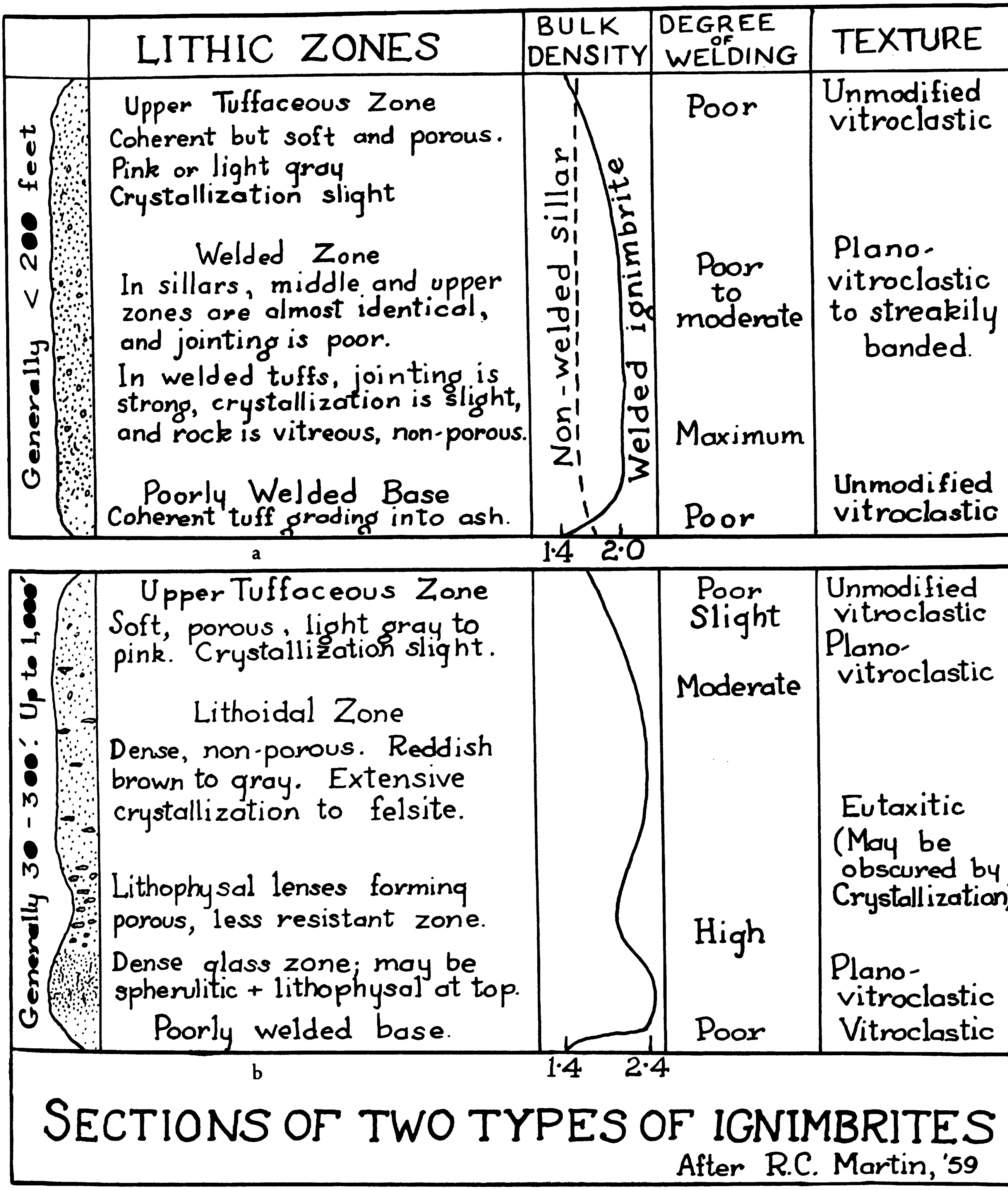


Figure 6. Vertical variations in ignimbrite sheets

a. Poorly zoned type
b. Strongly zoned type

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STONES USED FOR COLOSSAL SCULPTURE AT OR NEAR TEOTIHUACAN

Robert F. Heizer and Howel Williams

One of the most spectacular, and surely the largest, of all prehistoric stone sculptures in the New World is the unfinished Idolo de Coatlichán which until recently lay partly imbedded in the floor of a deep barranco not far from the Pueblo of San Miguel Coatlichán, Hacienda de Tepitlan, near Texcoco, on the eastern side of the Valley of Mexico. The monument first came to public notice in 1882, during which year it was "discovered," visited by a commission of archaeologists and artists, and an account of its finding published in the Anales del Museo Nacional de México (Sanchez 1882). As might be expected, the original article is full of wild speculation about the location of the ancient site at which the statue had been set up before it fell into the barranco. Recent excavation in the gravels in which the statue lay shows that it was sculptured on the spot and was never moved (Heizer and Williams 1963).

The monument, in the form of an upright human figure, is enormous (pls. 8 and 9). It is 7.1 meters long, 3.8 meters wide, and 4 meters thick, with a volume of about 81 cubic meters. The specific gravity of the stone from which it is carved being 2.43, its weight was calculated by us in 1963 as 197 metric tons or 217 short tons. In 1964, after long preparations which involved building a roadbed to the statue and manufacturing a special 112-wheeled trailer to carry the immense weight, the Idolo was removed to Mexico City and erected (pl. 10) near the entrance to the new Museo Nacional de Antropología in Chapultepec Park (Anon. 1964). The Mexican engineers calculated the weight of the statue as 168 metric tons. We believe that our calculation of 197 metric tons may be too great, but we also feel that 168 metric tons is too small—the correct answer must lie somewhere in between these figures.

The monument, which represents a stylized human figure, no doubt a god in human form, lay until 1964 on its back. Its immense size and the location made it impossible to secure an adequate photograph at the original site. The sculpturing appears not to have been carried to full completion, and the figure may be described as roughly finished but lacking final details and polishing. Its unfinished nature is most clearly evidenced by the presence of an attached pedestal or keel (pl. 10a) which, when the work was abandoned, was in the process of being removed to free the figure. The pedestal or keel is calculated by us as weighing 72 metric tons, and if subtracted, the figure's weight would be reduced to 125 metric tons or 137.5 short tons.

Why the monument was never completed and removed to a ceremonial center, which we may assume was the original plan, is a mystery. Perhaps the amount of labor needed to transport a stone of these dimensions was not available to those whose interests caused the sculpture to be fashioned. The suggestion has been made that flaws were discovered in the stone while it was being carved, and that these were serious enough to lead to the abandonment of the project. The extent to which the sculpturing had been carried out, as well as the absence of serious cracks in the stone, does not seem to us to support the theory of flaws. Actually we are in the dark as to the reason for the abandonment of the project before completion.

The monument is fashioned from a giant boulder of andesite. Many large boulders of similar lava—some of them three to four meters across—are present in the vicinity. All are imbedded in a crudely stratified or unstratified matrix of andesitic mud, silt, sand, and gravel derived from the higher slopes to the east. These waterlaid volcanic deposits are called lahars (a Javanese name) and are ascribed to powerful streams in flood which acquire and transport the boulders which are buoyed along by the torrents of mud. Such lahars are widespread, not only near Coatlichán but also among the large alluvial fans which descend from most of the high volcanic peaks to the Valley of Mexico. Everywhere these are interbedded with finer-grained alluvial fan deposits laid down by streams during times of more normal flow.

The boulders in the alluvial fans that descend towards the Pueblo of Coatlichán and Texcoco are unusually large because they were derived from the very thick flows of massive lava on the steep upper slopes of Cerro Tlaloc, a high, much-eroded Pliocene volcano whose summit (elevation 13,270 ft. a.s.l.) lies about 13 kilometers east-southeast of the site of the unfinished monument. Avalanches of large lava blocks may have accompanied the eruption of the thick flows, or alternatively, aprons of blocky talus may have developed by erosion of the lavas long after they were discharged. In any event, during times of exceptionally heavy rains large numbers of huge blocks were swept downslope in a matrix of finer debris, and it is from one of these that the Idolo de Coatlichán was fashioned.

All of the boulders in the laharic deposits near Coatlichán consist, as we have said, of essentially the same kind of andesite. Admittedly there are differences in color—some boulders are gray whereas others are reddish or brownish—but these differences, which reflect variations in the degree of oxidation by hot volcanic gases, are not important. We believe, therefore, that the following notes, based partly on field studies and partly on microscopic examination of thin-sections, will assist others in recognizing monuments carved from laharic boulders of the same provenience.

The Coatlichán andesite is a coarsely porphyritic, vesicular, pale gray lava characterized by many phenocrysts of dull white feldspar, most of them between 1 and 5 mm. in length. Dark minerals are relatively scarce. A few pyroxene prisms can be detected with the aid of a hand lens, and so may a few black pseudomorphs after hornblende.

The microscope reveals the lava to be a porphyritic, pilotaxitic, pyroxene andesite with resorbed hornblendes. About 25 to 30 per cent of a typical sample consists of phenocrysts of labradorite-bytownite which show intense oscillatory zoning. Slender prisms of hypersthene, occasionally 1 mm. long but generally less than half that length, make up about 6 per cent. Euhedral and subhedral crystals of hornblende, up to a maximum of 3 mm. in length, make up 3 per cent, but they are almost entirely replaced by magnetite or by magnetite intergrown with granules of augite. Prisms of augite less than 1 mm. long make up about 4 per cent, and microphenocrysts of magnetite about 2 per cent. The remaining 55 to 60 per cent of the lava is a pilotaxitic groundmass of oligoclase needles, interstitial cryptofelsite, specks of iron ore, and a little cristobalite. In one thin section the lava contains a xenocryst of quartz. In the field the rock is characterized further by the presence of sporadic, subangular, fine-grained basic (lamprophyric) inclusions up to fist-size.

The gigantic statue of the Diosa de Agua or Water Goddess (pl. 11*a*), so identified through the incised scrolls symbolic of water on the lower edge of her cape and skirt, has been, since 1889, one of the outstanding exhibits in the Museo Nacional in Mexico City. It is carved from a boulder of andesite identical in composition to that of the Idolo of Coatlichán.[1] The Water Goddess was first recorded in 1557 by Father Juan de Mendieta as lying half buried near the Pyramid of the Moon at the site of Teotihuacán. Mendieta reported another colossal figure lying on top of the Pyramid of the Sun, but this sculpture—if it ever existed—seems to have disappeared without being described. The Water Goddess statue was cleared of accumulated debris by the Mexican Commission under Almaraz (1864). Charnay (1881) gives the ill-fated Maximilian the credit for setting it upright. If the sculpture were discovered today, careful excavation would almost certainly throw light upon the cultural period, and therefore the date, in which it was erected at the site of Teotihuacán.

The Water Goddess statue, which stands nearly 4 meters high, weighs by our calculations about 24 metric tons or 26.5 short tons. It was reported to us in 1964 by the Directorate of the Museo Nacional, which supervised the recent transport of the Water Goddess from the old museum on Moneda to the new museum in Chapultepec Park, that the sculpture weighs 18 metric tons. Here, again, we have calculated a larger weight than the "official" one. Only careful measurements and calculations, which have not yet been made, will settle the question of the exact tonnage of this and the Coatlichán sculptures. Almaraz (1864 _in_ Holmes 1885:365) calculates the mass of the statue as 306.16 cubic feet, its density as 1.88, and its weight as 18 metric tons. The density figure is, however, too low and must be raised from 1.88 to 2.43. Using Almaraz' figure for volume and our corrected density figure, we can calculate the monument as weighing 23.8 short tons. We suspect that the "official" weight (i.e. the figure today quoted in Mexico) comes from Almaraz' calculation of 1864. Charnay (1881:366) says: "Its estimated weight is thirty-six thousand pounds"; and Thompson (1846:140) states: "The whole weight of the huge mass of porphyritic stone cannot be less than twenty-five tons." Covarrubias (1957) gives the weight as 22.4 metric tons (22,380 kg.), a figure apparently adopted from Seler (1961:435), and Beyer (1965:423) says it weighs more than 22 _toneladas_ (metric tons).

The absolute identity of the stone from which the Coatlichán statue and the Water Goddess were sculptured may be taken as evidence that the latter was transported from the Coatlichán area to Teotihuacán, a distance of about 25 kilometers. This statue could have been dragged down to the shore of Lake Texcoco, placed on a raft, and carried north by water to a point where land transport was again resorted to. Alternatively, it could have been dragged overland on a sledge from the source to the city.

There are available several formulae for the amount of human energy required to drag heavy stones. Applying the formula for computing the manpower needed to move Japanese megaliths devised by Kagamiyama (1955:32), one can determine that 730 men would be needed to drag the Water Goddess. Atkinson's formula, based upon the assumed energy requirements to move the sarsens at Stonehenge (Atkinson 1956:115), yields the figure of 530 men needed to drag the statue; and Heyerdahl (1959:134), who actually experimented with the transport of an Easter Island sculpture, would have used 360 men. In view of the size of the city of Teotihuacán there should have been no great problem in rounding up a labor force of 1000 men. Even the Coatlichán statue, which would have required by the formulae used above 1833, 2070, 3125, or 4025 men, could presumably have been moved if the Teotihuacanos had seriously wanted to do so.

While the conclusion that the isolated Coatlichán statue is to be associated with the site of Teotihuacán is not new, the reason for believing this was the case because of the use of a particular kind of stone is something not known before. Earlier opinions that the Coatlichán Idolo was a Teotihuacán sculpture rested upon stylistic considerations. The two statues are similar in their tremendous size and in the angular "block-and-panel" style of carving. But the specific differences are numerous. Where the Coatlichán figure has a depression 50 cm. deep in the top of the head (pl. 9b), the Water Goddess has a smooth, flat top with a front-to-back V-shaped groove (pl. 11a) which is reminiscent of the notched foreheads of some Teotihuacán II period clay figurines and may represent the hair parting. The Water Goddess stands flat-footed on a square pedestal, but the Coatlichán statue rests on its own two flat feet, each of which covers an area of about 24 square feet. The treatment of the face cannot be compared because this portion had been anciently defaced by hammering in the Coatlichán statue (pl. 10b), but the two are clearly quite different. Both figures are generally believed to be identifiable as water deities although, as Carmen Cook de Leonard in Mexico City has suggested to us, the hollow in the top of the Coatlichán monolith could have been used as a receptacle for water if the stone were a water goddess, or a brazier if it were a fire goddess. Recent newspaper and Life magazine (Anon. 1964) accounts of the removal of the statue refer to it as Tlaloc, the god of rain. Kubler (1962:33) notes that the identification of the Water Goddess as such "is supported only by the meander hems of the skirt and cape which bear a repeating scroll that signifies liquid in the murals and vase painting." The identification of the statue as the goddess of water was first made by Sanchez (1882), according to Beyer (1965:420-421). Chavero (1904) notes that the local Indians identified the statue in 1874 as representing the "diosa del agua," and after an exhaustive review of the evidence, he comes to the conclusion that the Coatlichán statue is not Tlaloc (ibid. 292) but a female figure identifiable as Chalchiuhtlicue, the goddess of water (ibid. 301). If he is correct, and his arguments seem to be excellent, both the Water Goddess statue and the Idolo de Coatlichán represent the same deity of the Teotihuacanos.[2] Starr (1904:259) summarizes the various opinions of Batres (1903), Chavero (1904), and Becerril (1903) on the identification of the Coatlichán sculpture either as Tlaloc or Chalchiuhtlicue. Further reference to this controversy can be found by consulting Bernal (1962, items 4397, 4487).

Kubler (1962:33) believes that the Water Goddess originally served as a pillar or caryatid to support wooden roof beams, and while this is possible, there is no evidence that this monolithic sculpture did serve as an architectural support. While it is possible that only one such anthropomorphic pillar might have been used as Kubler suggests, it is difficult to imagine in what way such a single support could have served in any of the known Teotihuacán structures. Certainly it would have been more visually impressive as an unencumbered, free-standing form placed in front of a structure. One questions whether the narrow fore-and-aft groove in the top of the statue could have served to do more than carry a single beam. The flat top surface of the statue shows no abrasions, polishing, or other features to suggest its use as a beam rest. The Water Goddess, done in a block-and-panel style, was made to be viewed from the front—she has no profile to speak of—and this convention makes it similar to many of the mural paintings at Teotihuacán, especially to what are interpreted as rain figures at the Tetitla group which belong to the Teotihuacán III period, or in the now destroyed mural in the Temple of Agriculture, of which we have a copy made in 1884 (Seler 1961:pl. VII, fig. 2; Marquina 1951:pl. 23). The Temple of Agriculture mural is a busy scene with three horizontal registers of alternately seated and walking costumed humans, bordered on each side by two colossal pier-like statues which look very much like the Water Goddess, and in front of which are what appear to be pyres from which issue smoke and flame. Kubler dates this mural, on typological grounds, as the earliest at Teotihuacán and places it in Period II which would now be dated at A.D. 100-200. We do not know how accurately the 1884 copy reproduces the original mural, and the human figures are so much like those to be seen in the codices of the Conquest period that one wonders whether the copyist of eighty years ago did not use the latter rather than the original mural as his model. A Teotihuacán III date for the Water Goddess is suggested by Kubler, who believes that its association with the Pyramid of the Moon implies a middle Classic date of about 500 A.D., but a recent proposal by Millon and Drewitt (1961), that the Pyramid of the Moon was built in the Teotihuacán II period, would make the Water Goddess, by the same association, perhaps 300 years earlier.

The Water Goddess is believed by Miguel Covarrubias (1957:131)[3] and Salvador Toscano (1952:211-213), and probably by Krickeberg (1949: 199-206), to date from Period II or Miccaotli, while Eulalia Guzmán proposes (1959:968-969) that the statue shows a close stylistic relationship with the Atlantean Warrior Columns at the Toltec capitol of Tula and is therefore of Toltec manufacture, of post-Classic date, and was brought to Teotihuacán <u>after</u> the abandonment of the city about 800 A.D. The Water Goddess and the Tula Warrior Columns may have served as architectural supports, but beyond this generic functional parallel, which is not proved, there are more differences than similarities between the quarry-block monolithic Water Goddess and the more literally representational Tula columns which are built up of sections. Guzmán's theory has little to recommend it, and ignoring it, we may choose between a Teotihuacán II dating derived from stylistic similarity of the statue with early mural paintings and its association with the Moon pyramid, or a Teotihuacán III dating through similarity with murals in the Tetitla suburbs of Teotihuacán. For what it is worth, we incline to a Teotihuacán II date for the Water Goddess.

The first detailed description of the Water Goddess statue was by Almaraz (1864), but there were earlier, and useful, brief accounts by Charnay (1881), Mayer (1852), and Bancroft (1885:540-541). The great W. H. Holmes (1885) provided the first adequate description based upon observations made in 1884, and settled the problem of identification of the colossal sculpture called the "fainting stone" by several earlier authors by showing that these writers were only referring to the plain back and sides of the prostrate Water Goddess statue.

A third sculpture formed of the Cerro Tlaloc andesite is known and deserves mention. This is a partially sculptured boulder (or perhaps a badly mutilated sculpture)[4] which now stands in the middle of the Avenue of the Dead at Teotihuacán, about 200 yards south of the Pyramid of the Moon (pl. 11b). It is 1.7 meters high, 1.5 meters in diameter, and weighs about 6 metric tons. Its chief importance lies in attesting to the additional importation of this particular kind of stone, and in evidencing a pectoral cavity for the insertion of a stone symbolizing the heart and a wide collar of three strands of tubular beads, both of which features also occur on the Water Goddess sculpture.

The two sculptures at Teotihuacán (the monolithic Water Goddess and the smaller, incomplete or defaced figure called by Holmes the "prostrate monolith") can be shown to have been made from the distinctive andesite that is derived from the Cerro Tlaloc, about 25 kilometers to the south. On the lower slopes of the same Cerro Tlaloc lies the unfinished Idolo de Coatlichán whose general style is so strongly reminiscent of the Water Goddess that it seems probable that the original plan was to transport this third statue, when finished, to the site of Teotihuacán. The Water Goddess, as well as the "prostrate monolith," probably dates from Teotihuacán II (100-200 A.D.) as judged from their association with the Pyramid of the Moon and the northern end of the Street of the Dead. Since the little known Teotihuacán I period dating from the first century A.D. has not thus far shown evidence of monumental sculpture, the Coatlichán statue probably does not belong to this period. The Water Goddess is sufficiently different stylistically from the Coatlichán monolith that we may suggest the latter dates from the late- or post-Teotihuacán II Tlamimilolpa phase (200-300 A.D.), or the Teotihuacán III period (300-600 A.D.). There is nothing to suggest that the failure to complete the Coatlichán monument and move it to Teotihuacán was due to the disruption of life that finally caused abandonment of the great urban center about 800 A.D., but the possibility cannot be ignored that the explanation for its relinquishment lies in a social or religious change at an earlier date.

This review shows how slight the evidence can be for dating portable sculpture, particularly in a site which has been so badly excavated and studied as Teotihuacán. It is said that no pottery was encountered beneath the Coatlichán sculpture when excavations were made to expose it preparatory to its transport to Mexico City. Such neatness on the part of what must have been a large group of sculptors who anciently worked on the statue is hard to believe, and if the report is accurate, we can only marvel at the extraordinary care which must have been taken not to contaminate or defile the sacred work and site with profane trash. In this case we can point to a difference of attitude in later Mexican prehistoric societies, and an approach to something like the ascetic cleanliness evidenced in the bare rooms of the temple structure at Tikal. Unfortunately this point cannot be pressed because of the uncertainty of the facts in the case.

NOTES

1. Holmes (1885:363) identifies the stone as a "dark gray porphyritic trachyte or andesite, in which are enclosed a number of large brecciated fragments of light-colored rock." Mayer (1852:II:281) calls it "granite"; Mendoza (cited by Holmes 1885:366) referred to it as "a trachyte of doubtful variety"; Charnay (1881:366) calls it "trachyte"; Butler (1885:149) identifies it as "gray granite"; Batres (1903) classed it as "hornblende andesite"; Beyer (1965:423) in 1920 simply called it "stone of volcanic origin"; and Kubler (1962:37) calls it "basaltic lava."

2. For a discussion of the beliefs attached to the Cerro Tlaloc and a description of the "temple" on its summit see Wicke and Horcasitas (1957).

3. Covarrubias (1957:pl. 28) is wrong in identifying the Water Goddess and the Idolo de Coatlichán. This is a posthumous work and the mistake is therefore not attributable to the author.

4. Holmes (1885:362-363) conformed to "the generally accepted view that this city was conquered and destroyed by the Spaniards, although as Mr. Bandelier has suggested, there may be grounds for doubt on this point." By accepting this view, now known to be incorrect, Holmes thought it likely that the iconoclastic conquistadores had "battered with hammers or scaled off by fire" the details of the sculpture of this piece. Our impression is that there has been deliberate mutilation of the sculpture but that it must represent pre-Conquest iconoclasm. This piece is illustrated here in Plate 11*b*, and has earlier been shown in a sketch by Holmes (1885:fig. 10) and in a photograph by Seler (1961:pl. XVII, fig. 2).

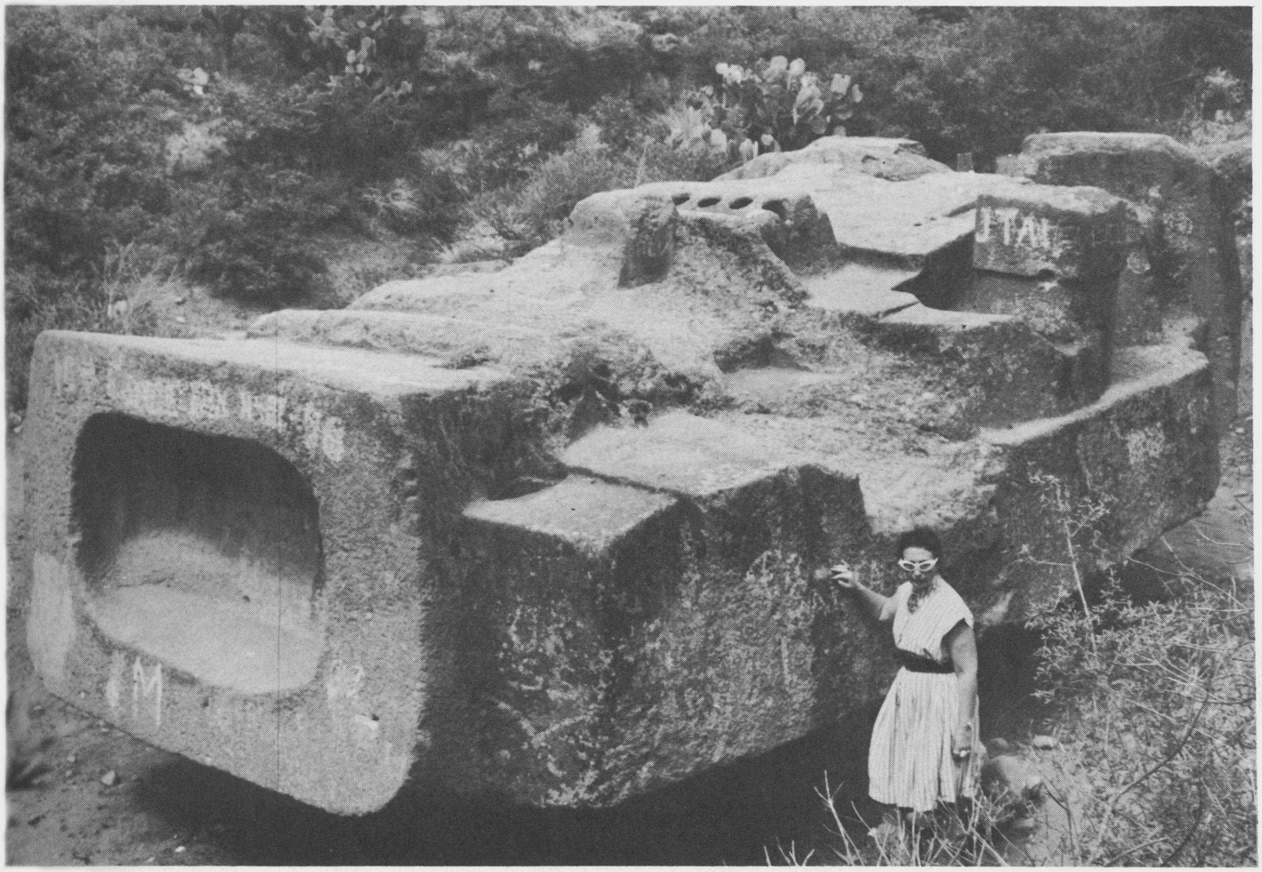
a

b

Plate 8

The Idolo de Coatlichán in situ before its removal to Mexico City

a

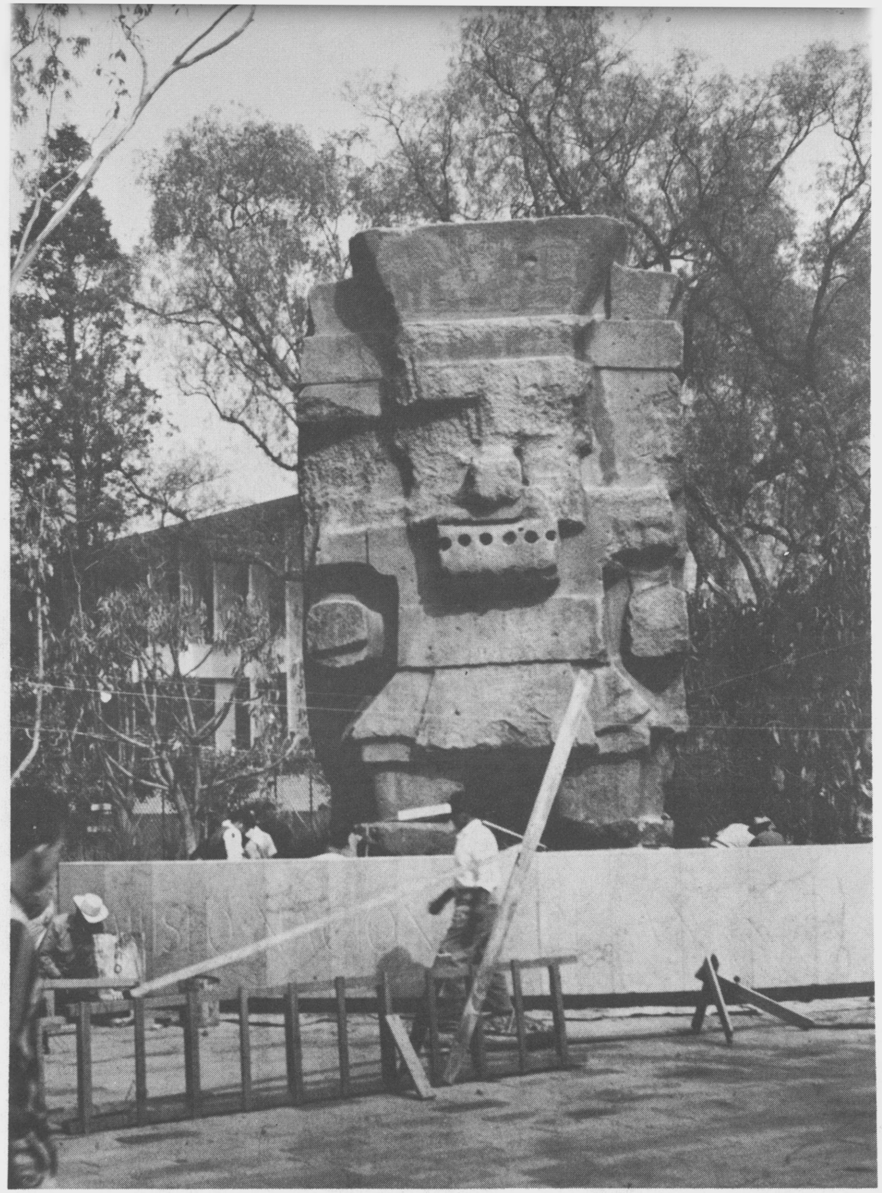


b

Plate 9

The Idolo de Coatlichán in 1962

a

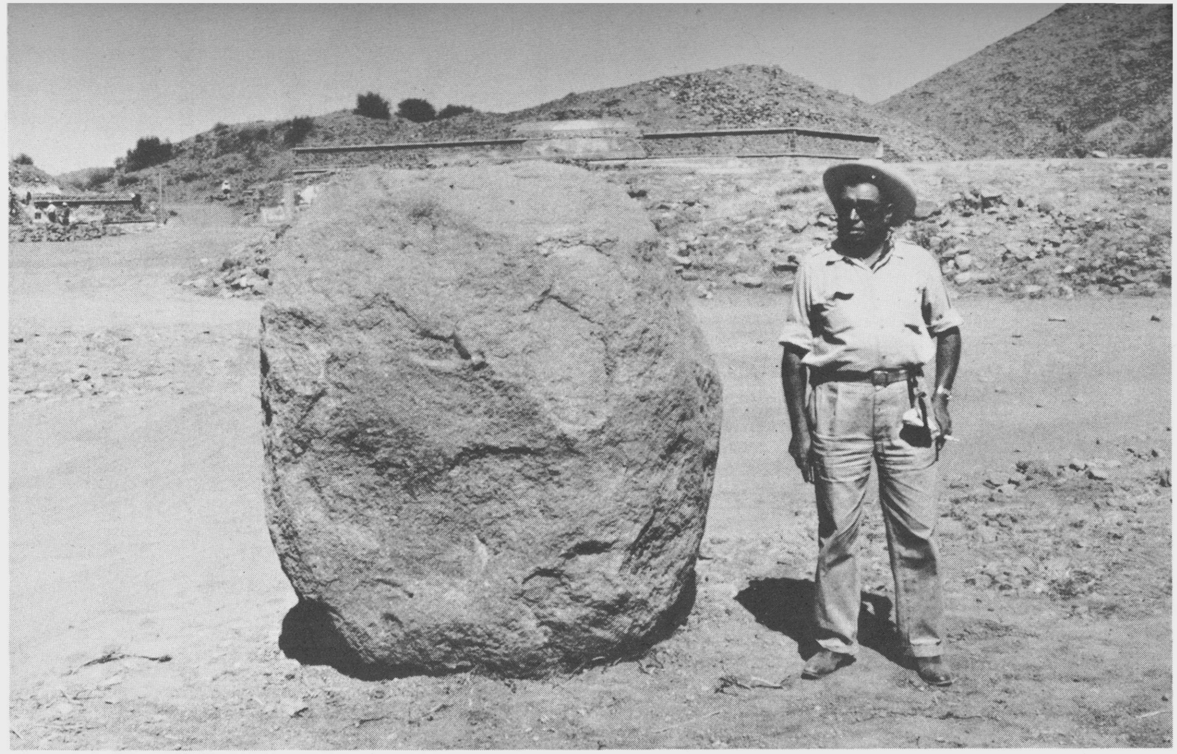


b

Plate 10

Erection of Idolo de Coatlichán at entrance to Museo Nacional de Antropología, Mexico City

a



b

Plate 11

_a_. Diosa de Agua

_b_. Prostrate monolith (view of unsculptured rear)

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OLMEC SCULPTURE AND STONE WORKING: A BIBLIOGRAPHY

Robert F. Heizer and Tillie Smith

Since 1869 a distinctive sculptural style in jade and other stone media, now known as Olmec, has been vaguely recognized. However, it was not until 1938 that Dr. Matthew W. Stirling, then Chief of the Bureau of American Ethnology of the Smithsonian Instituion, began to excavate and bring to light substantial archaeological evidence of this culture. The history of the development of Olmec studies has been sketched by Drucker, Heizer and Squier (1959) and Jones (1963:1-2). While Olmec can properly be called a culture, it is important to note that it is primarily definable through its distinctive art style. The excavation of the site of La Venta (Drucker 1952; Drucker, Heizer and Squier 1959; Stirling 1940 *et seq*.) has provided us with excellent information regarding the architectural aspects of Olmec culture, but to date no adequate study has been made of the homely or prosaic pursuits of the people who built and maintained the great ceremonial centers of Tres Zapotes, San Lorenzo, and La Venta. Thus, while we can infer something about the techniques employed in working jade or sculpturing large stone monuments from an inspection of the pieces themselves, we are quite in the dark as to where such work was done or what instruments were employed in stone working.

In connection with the research which we have done in an attempt to discover the sources of the stones used by the Olmecs of the southeastern Mexican lowland, we believe it to be expedient to include here a reference bibliography of Olmec stone sculpture. No suggestion is made that the bibliography is a complete one, but the student interested in the subject can surely find a majority of known Olmec pieces illustrated and/or described in the references which are listed here.

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ANALYSIS BY X-RAY FLUORESCENCE OF SOME AMERICAN OBSIDIANS

J. R. Weaver and F. H. Stross[1]

Analysis of minor or trace components of minerals has shown that the relative concentrations of these components often are uniquely characteristic of the source of the mineral, while those of the major components, e.g. silica or alumina, are not. In the case that there exist relatively few sources of the mineral but relatively many sites on which artifacts made from this mineral are found, such analysis can provide significant information on the mode of distribution and related attributes of the object. Obsidian is an example of such a mineral; a recent analytical study of European, Asian, and African obsidians (Cann and Renfrew 1964) has evolved information of the type mentioned. Recently developed instrumental methods of analysis are highly sensitive and rapid, and can often be carried out without damage to the specimen. It is the object of this and the following paper to describe the application of a technique of this kind aimed at relating obsidian objects found in Middle America to putative sources of the mineral, and to distinguish the sources from each other. This, we hope, will provide insight into the mutual contact of the various cultures with each other in prehistoric times.

Obsidian has also lent itself to other types of examination. A fresh surface of obsidian absorbs water from the ambient to form hydration layers (Friedman and Smith 1963) that can be measured under the microscope. The hydration begins when the piece is chipped or flaked, and continues at a knowable rate. Measurement of the thickness of the hydration layer thus provides an estimate of the time elapsed since the surface was worked. The rate of hydration is affected by the average temperature of the site (corrections are easily applied), but the average relative humidity seems to have no significant effect because there is always enough water in a natural ambient to saturate the outer surface with a molecular film of water. This technique, then, may be useful in direct dating of an artifact, but the analytical method to be described here is to be applied to correlations of a quite different kind.

To attain our objective, we must find the distinguishing components that are similar in concentration within a source, but differ between

[1] Shell Development Company, Emeryville, California.

sources. To ascertain the presence of such components a limited number of carefully chosen obsidian materials from the same, and from different, sources and a few artifacts found on different sites were subjected to analysis. In view of the promising and consistent results, a more detailed study has been planned.

The successful correlation obtained by Cann and Renfrew (1964) was based on the analysis of obsidian by means of optical emission spectroscopy. The use of that method represented a real advance over conventional chemical analysis since it permits the detection and determination of about seventy elements in a mere fraction of the time required by the latter methods. This suggested to us that an additional saving in time might be effected by the use of the x-ray fluorescence technique. It has attained much favor in recent years because of the great rapidity with which many kinds of samples may be analyzed; all elements having atomic numbers greater than 11 (Na) can be detected with conventional apparatus.

METHOD

The x-ray fluorescent method is simple both in principle and practice. When atoms are irradiated with sufficiently energetic x-rays, each different kind of atom emits a characteristic spectrum of x-rays; these x-rays are sorted according to wavelength, by means of a crystal, analogous to the sorting of visible light by means of a diffraction grating, and they are detected by electronic devices. In practice, the sample, either as a solid or in solution, is placed in a cell and its spectrum recorded on a strip chart. This gives a sort of "finger print" analysis, and is the technique applied in this study. In the more elaborate quantitative mode of operation, careful intensity measurements are made at discrete wavelengths without recording the complete spectrum.

The instrument used was a General Electric XRD-6 with a chromium-target tube operated at 50 kv and 60 ma. In order to record the entire region of interest, two scans were made on each sample. A lithium fluoride crystal (2d = 4.0267 A) and a dual flow proportional counter - scintillation counter were used to cover the range 5° to 145° (2 θ); EDT (ethylenediamine tartrate) crystal (2d = 8.8030) was used with the flow proportional counter and a helium path to record the range 60° to 145° (2 θ). Both scans were made at the rate of 2° (2 θ) per minute.

Fragments of the obsidian were ground to a fine powder in an alumina-lined vial. The vial, containing the chips and an alumina ball, was shaken by means of a Spex Industries Mixer/Mill (Model 8000) for ten minutes. A shallow container was filled level full with powdered sample (about 2.5 g), inserted into the instrument, and the fluorescent peaks were recorded on the strip chart. Every recorded peak was identified and its approximate intensity in terms of counts per seconds was read from the chart.

Results

Nine specimens of obsidian were analyzed; the results are shown in Table 2. It is most important to understand that the units are observed counts per second for specific lines ($K\alpha$ in every case except Ba, where $L\alpha_1$ was used), and that a given concentration of one element will not necessarily produce the same count rate as the same concentration of a different element. In other words, it is possible, from these data, to deduce differences between samples, but not differences between elements.

DISCUSSION

Study of Table 2 reveals some interesting differences in composition of obsidians from different sources, and some rather striking similarities between the artifacts believed to be from the Pachuca source (Numbers 6 and 7) and the Pachuca mineral specimen (Number 3). It is also encouraging to note the chemical similarities between the Papalhuapa specimens (Numbers 4 and 8) despite the gross difference in physical appearance (black and red).

The data are suggestive but by no means conclusive. The usefulness of the technique could only be demonstrated by analyzing numerous samples from each of the various sources of obsidian. One hopes that a distinctive and consistent composition will be found within each source, but even if this is not so (and it is unlikely), a single element may serve as the distinguishing characteristic. Since the x-ray fluorescent procedure is so rapid and is capable of detecting many elements even at low concentrations, it seems an ideal method for examining many samples in the essential process of finding which elements provide valid correlations. Although the instrument time was approximately two hours per sample, the time required of the operator during the recording process is trivial; with a little practice the analyst can probably identify and measure the significant peaks in about fifteen minutes per sample.

Table 2. X-RAY FLUORESCENCE ANALYSES OF OBSIDIAN

Units: Counts/second above background

1 = "Glass Mt., Napa Co., Calif." (Mineral)
2 = "Site Sol-2, Solano Co., Calif." (Mineral)
3 = "Pachuca, Hidalgo, Mexico" (Mineral)
4 = "Papalhuopa, Jutiapa, Guatemala" (Mineral)
5 = "Copan" (Artifact)
6 = "Teotihuacan, green obsidian presumed to be from Pachuca source" (Artifact)
7 = "La Venta green obsidian (from Pachuca source?) (Artifact)
8 = "Red obsidian from Papalhuapa" (Mineral)
9 = "El Chayal obsidian - Guatemalan (second Guatemalan source)" (Mineral)

	1	2	3	4	5	6	7	8	9
Zr	210	205	720	160	120	600	800	150	110
Nb	30		85			60	70		
Rb	140	165	140	80	65	160	150	80	120
Sr				110	90	20		140	110
Cu	135	145	135	150	135	135	160	135	145
Zn	25	32	78	15		85	75	20	25
Ni	18	23	25	15		25	25	20	25
Fe	1130	1140	1880	1080	1060	1900	1940	1180	780
Co	Trace					Trace	Trace	15	15
Cr[a]	840	820	820	750	760	810	840	740	740
Mn	90	80	180	.170	110	180	200	120	35
Ba	32	25	Trace	65	60			65	50
Ti	75	60	140	170	150	145	150	160	120
Ca	85	70	30	230	208	35	35	245	130
K	340	370	305	345	325	360	345	370	330
Cl	100	150	200	90	90	180	150	40	60
Si	1480	1410	1360	1440	1260	1380	1290	1460	1520
Al	510	490	510	510	500	480	450	430	400

a) Most, but probably not all of the Cr intensity is from the Cr target x-ray tube. The difference between samples may still be significant.

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NOTES ON MESOAMERICAN OBSIDIANS AND THEIR SIGNIFICANCE IN ARCHAEOLOGICAL STUDIES

Robert F. Heizer, Howel Williams and John A. Graham

Prehistorians are interested in obsidian as a material from which artifacts were fashioned partly because the natural occurrence of this volcanic glass is rare and these few source localities have constituted a supply of trade material (Bosanquet 1904; Sarasin 1936). Archaeologists who have studied obsidian trade have been hopeful that chemical differences in obsidians from various sources might enable them to identify with certainty the original place from which imported obsidian found in archaeological sites was obtained. Unfortunately, however, ordinary chemical analyses of different obsidians are so much alike that this method of identification does not appear to be very promising. In certain instances obsidians contain significantly larger or smaller amounts of some specific element which enables one to identify the source (cf. Washington 1921, tables 1, 2), but these cases are the exception rather than the rule as one can tell from casual inspection of tables of chemical analyses. For illustration we provide here such a table drawn from published information provided by Williams, McBirney and Dengo (1964:43), Washington (1921), and unpublished data provided by Carl Fries, Jr., Instituto de Geología, University of Mexico. The analyses forwarded to us by Dr. Fries were made for him by Ing. Alberto Obregon-Perez, chemist of the Instituto de Geología. Ordoñez (1892) characterized six different obsidians of Mexico by identifying different forms of microlites in them. This approach to identification may be a useful one and perhaps deserves more attention than it has received. Washington (1921:482, 484) provides the refractive indices as determined by the immersion method for obsidian from Copán and Chichén Itzá. The two are sufficiently different to suggest that this characteristic might also be useful in distinguishing different obsidians.

In January, 1965, the authors spent two weeks in Guatemala visiting archaeological sites and conducting a site survey in the area of the volcano of Ixtepeque, Department of Jutiapa. We encountered widespread evidence of ancient obsidian-working in and near the village of Papalhuapa which lies near the base of Ixtepeque. This obsidian locality has been described by Williams, McBirney and Dengo (1964:38-42). It is obvious that the Ixtepeque source was extensively exploited and that the obsidian was collected for export purposes.

On our return to Berkeley we approached Mr. J. R. Weaver and Dr.

F. H. Stross for their suggestions on a method which could be employed to distinguish individual or local obsidian types. They proposed the use of x-ray fluorescence which has been known for some time as useful in mineralogical determination (Ashby 1961; Anon. 1958) and archaeological analysis (Hall 1960), and we submitted to them a limited series of samples which were selected to test the applicability of the method. The results of their examination are given in the preceding paper. While we were engaged in this laboratory work we received a copy of the paper by Cann and Renfrew (1964) which approached the same problem by a different method. The results of our method and of the Cann-Renfrew method are similar, and it is clear that by using either one it is possible to identify a piece of obsidian as coming from a specific source locality. There are thus available at least two means of determining how far in space obsidian from a given locality was diffused. We intend to continue our investigation of Mesoamerican obsidians along this line, and have begun to collect samples for testing.

We provide here a map showing the location of presently known obsidian localities in Mexico and Guatemala. There are, possibly, additional occurrences which are not indicated here, but at the same time it is probable that most of the important localities which were known and exploited in prehistoric times are indicated on Map 5.

Presented below are a few comments on the possible significance of the analyses provided by Weaver and Stross in Table 2 of the preceding paper.

Sample No. 1 comes from the obsidian locality called Glass Mountain which is near St. Helena, Napa County, California. This site has been described earlier (Heizer and Treganza 1944:303-306, map 1, figs. 5A, 5B, 7; Heizer, ed., 1953:248, site 31). It has always been assumed that the Glass Mountain obsidian was traded south and east to San Francisco Bay and the lower Sacramento Valley areas. To test this assumption Sample No. 2, from a Late Horizon site (Sol-2) was submitted for analysis, and in our opinion the results support the belief that the obsidian from site Sol-2 did in fact come from the Glass Mountain locality.

Sample No. 3 was collected by W. H. Holmes (1919:214-226) at Pachuca, State of Hidalgo, Mexico. We are indebted to Dr. Clifford Evans of the U.S. National Museum for providing us with this specimen from the well known obsidian locality which is also referred to as "Cerro de las Navajas" and "Mountain of the Knives." This obsidian is characteristically green in color, and it has been generally assumed whenever implements of this green obsidian occurred in Mexican sites that their source was the Pachuca flow. We provided Weaver and Stross with two additional samples of green obsidian, one an exhausted nucleus from Teotihuacán (Sample No. 6) and the other a small blade ("razor") from the site of La Venta, Tabasco (Sample No. 7), in the hope that we could discover whether all three were, as expected, so similar as to be considered derived from the same locality. Samples Nos. 3, 6, and 7 are sufficiently close in their trace element composition to indicate the strong probability, if not certainty, that this is a fact. Since the La Venta site is three hundred miles distant from Pachuca we have clear evidence of long range trade. The La Venta sample is not, unfortunately, accompanied with archaeological context, and we cannot say whether it dates from the period of the La Venta ceremonial site of about 800-400 B.C. or from after the abandonment of the ceremonial center, in which case the sample would be younger than about 2300 B.P. At the moment, therefore, we must be satisfied simply to know that Pachuca obsidian was traded as far away as La Venta.

Sample No. 4 is from the Guatemalan Ixtepeque obsidian deposit mentioned above, and the reason for determining its trace element characteristics is to learn whether it is distinctively different from Sample No. 9 which is from the extensive, though very much smaller, deposit at El Chayal in Guatemala which was mentioned by Holmes (1919:227) and described in greater detail by Coe and Flannery (1964). We also submitted a second Ixtepeque obsidian sample, Sample No. 8, which was red obsidian. By comparing the analyses of Samples Nos. 4 and 8 we can see that the two are very similar, and from this conclude that color variations such as red and black in the same obsidian deposit are visual rather than chemical differences. Sample No. 9, from El Chayal, appears to differ sufficiently from Samples Nos. 4 and 8 that it is possible to distinguish them.

Sample No. 5, a thin blade of black obsidian, came from Copán, and was made available through the kindness of Dr. H. Pollock from the collections of the Peabody Museum, Harvard University. Since it is fairly obvious that a great deal of worked obsidian in the form of implements, and perhaps raw material chunks or blanks, was exported from the Ixtepeque locality, we considered it possible that Copán might have secured obsidian from Ixtepeque. Washington (1921:481) suggests that obsidian occurs naturally in the immediate vicinity of Copán, but this is very much to be doubted; in any case no geologist has ever observed either obsidian flows or nodules imbedded in the ignimbrites in the Copán vicinity. The question cannot be answered on the basis of the very limited number of samples analyzed by Weaver and Stross; it is only possible to say that the Copán implement may have been derived from Ixtepeque, and that it was almost certainly not derived from the El Chayal locality.

Nothing offered here can be considered more than suggestion. It is, as Weaver and Stross point out, only after numbers of samples from each source locality are analyzed that we can know for certain what range of trace element characteristics for different obsidians exists. Cann and Renfrew (1964) have analyzed a very much larger series of obsidian samples from the Mediterranean region and were able to establish six major groups of obsidians. They have also been able, as we hope ultimately to do, to draw important culture-historical conclusions from their data. For our part, at this time we can only say that we believe x-ray fluorescence analysis will provide us with the same sort of useful data.

EXPLANATION OF MAP 5

Principal Obsidian Localities of Mexico and Guatemala
(Numbers refer to localities indicated on map)

No. 1 On highway from Guadalajara to Tepic; near town of Tequila. This locality is called Sierra de la Venta, near Magdalena, Jalisco, by West (1964:47).

No. 2 On highway from Zinapecuaro to Ciudad Hidalgo; just south of Zinapecuaro, Michoacan. This locality is called Sierra de San Andrés, near Ucareo, N.E. Michoacan, by West (1964:47).

No. 3 Near Cadareyto de Montes, Queretaro.

No. 4 Small cut with abundant material on road from Pachuca to Zacualcipan, Hidalgo; at the turnoff to Huayacocotla to the east.

No. 5 Las Minillas, Cerro de las Navajas; north of Cuyamaloya and east of Pachuca. Locality described by Holmes (1919:214-226) and Breton (1902).

No. 6 Obsidian exposed in cut on highway from Tulancingo to Posa Rica, Veracruz; between 145 and 146 km. markers.

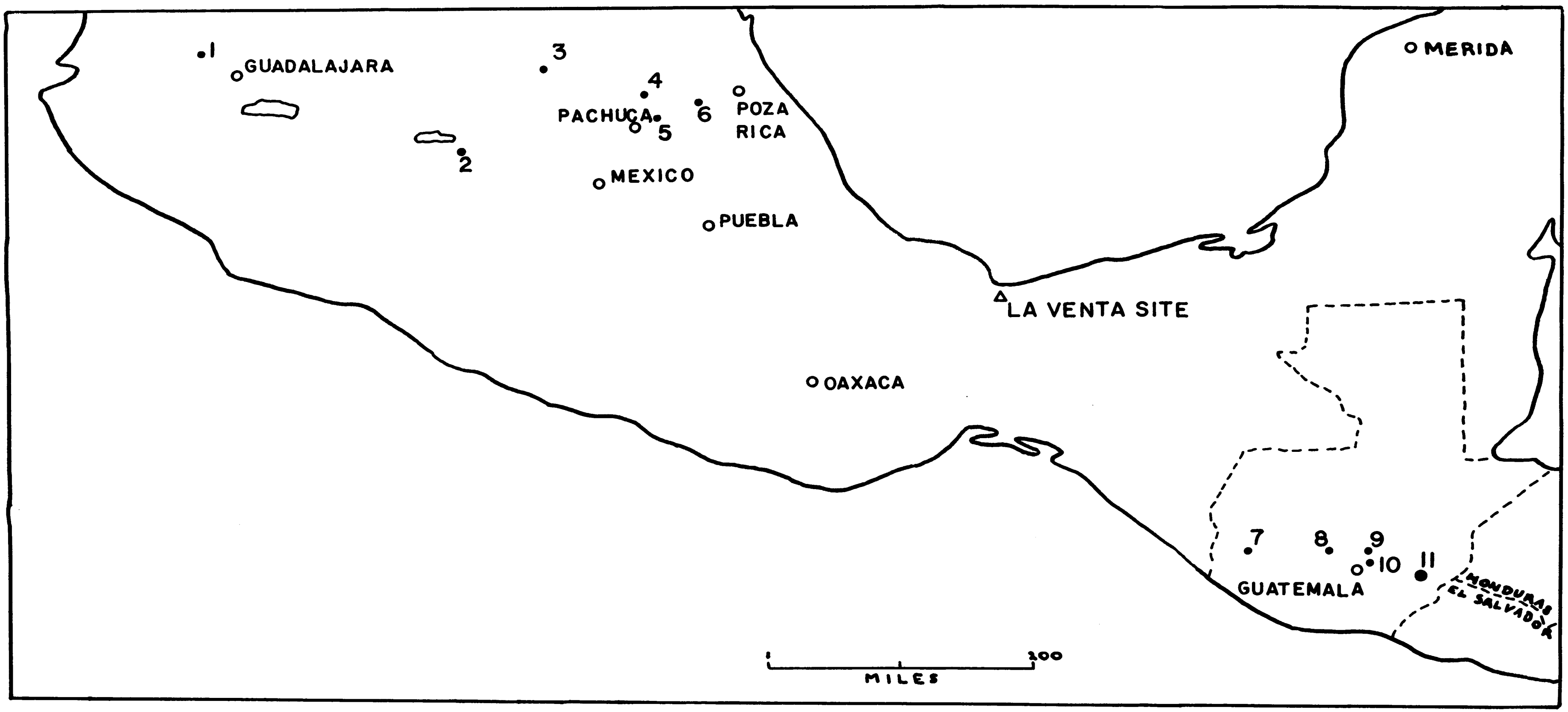
No. 7 Four miles southeast of town of San Pedro and approximately five miles east-southeast of San Marcos. Information taken from map in McBryde (1947).

No. 8 On road between San Martín Jilotepeque and Chimaltenango; 14 km. south of S.M. Jilotepeque and 17 km. north of Chimaltenango.

No. 9 El Chayal, near El Fiscal. Atlantic Highway from Puerto Barrios to Guatemala City cuts through exposures of obsidian. Area mentioned by Holmes (1919:227) and more fully described by Coe and Flannery (1964).

No. 10 On old highway to Sanarato, north of the Agua Caliente bridge.

No. 11 Ixtepeque volcano, Laguna de Obrajuelo and Agua Blanca area, southeast Guatemala. This is the largest of all obsidian areas in Middle America and probably the largest locality in the world. Described by Williams, McBirney and Dengo (1964).



Map 5

Principal Obsidian Localities of Mexico and Guatemala

EXPLANATION OF TABLE 3

Sample 1	Mexico: Site 6, Map 5. Analyses 1 through 6 were made by Ing. Alberto Obregon-Perez, Instituto de Geología, University of Mexico.
Sample 2	Mexico: Site 5, Map 5.
Sample 3	Mexico: Site 4, Map 5.
Sample 4	Mexico: Site 1, Map 5.
Sample 5	Mexico: Site 2, Map 5.
Sample 6	Obsidian knife from Teotihuacán, identical in color and luster with obsidian from Site 5, Map 5.
Sample 7	Nearly colorless obsidian from flakes of broken knives collected near Petlalcingo, Puebla, and north of Telixtlahuaca, Oaxaca, Mexico.
Sample 8	Obsidian implement from Copán, Honduras. After Washington 1921, Table 1.
Sample 9	Obsidian from Corinto, Nicaragua. After Washington 1921, Table 1.
Sample 10	Cerro de las Navajas, Mexico (same as Sample 2), Site 5 on Map 5. Compare with Sample 2, this table.
Sample 11	Cerro de las Navajas, Mexico (same as Samples 2 and 10 this table), Site 5, Map 5.
Sample 12	Ixtepeque volcano, Guatemala. After Williams, McBirney and Dengo 1964, table on p. 42, col. 1.
Sample 13	Crater of Laguna de Obrajuelo, Guatemala. After Williams, McBirney and Dengo 1964, table on p. 42, col. 2.
Sample 14	Obsidian bead from cenote at Chichén Itzá. After Washington 1921, Table 2, col. 1.

TABLE 3

Chemical Composition of Some Mesoamerican Obsidians

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	73.65	74.63	73.72	74.56	75.43	74.78	75.50	74.46	76.68	75.23	75.64	73.08	72.67	75.58
TiO_2	0.29	0.28	0.31	0.25	0.12	0.29	0.16	0.45	-	-	-	0.26	0.21	0.10
Al_2O_3	12.80	11.43	13.32	13.15	13.04	11.46	13.60	13.13	14.49	12.36	12.68	12.99	13.20	9.67
Fe_2O_3	0.60	1.70	0.85	0.51	0.51	2.13	0.12	0.49	-	0.96	1.07	1.20	0.43	2.23
FeO	1.76	0.61	0.76	1.00	0.76	0.46	0.45	1.03	1.09	1.24	-	1.62	0.56	0.83
MnO	0.02	0.01	0.02	0.02	0.02	0.06	0.05	0.05	trace	-	-	0.06	0.01	trace
MgO	0.25	0.36	0.22	0.25	0.15	0.25	0.19	0.29	0.84	0.01	trace	0.43	0.23	0.21
CaO	0.63	0.00	0.66	0.66	0.43	0.00	0.45	1.25	1.53	1.00	0.83	1.22	0.78	0.72
Na_2O	4.28	5.43	3.13	4.10	4.73	5.73	4.48	4.52	3.92	4.00	4.98	3.84	2.99	5.13
K_2O	5.15	5.17	6.60	5.44	4.57	4.42	4.62	4.37	1.20	4.62	3.51	4.06	4.51	4.56
H_2O+	0.23	0.38	0.22	0.25	0.51	0.39	0.26	0.10	0.36	0.73	1.58	0.89	4.22	0.38
H_2O-	0.01	0.03	0.03	0.06	0.00	0.05	0.09	0.03				0.36	0.27	
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	0.04	-	-
P_2O_5	0.08	0.08	0.09	0.08	0.06	0.06	0.02	0.09	-	-	-	0.13	0.01	-

- = no determination made

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